CHARACTERISTICS

OF

ONGOING AND INDUCED TINNITUS

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ABSTRACT

The present study investigated various characteristics of ongoing and induced tinnitus. Subjective descriptions, severity ratings, loudness matches, pitch matches and masking levels of tinnitus and induced tinnitus were obtained. Masking of tinnitus was attempted with a white noise, a tone at the matched tinnitus frequency and tones at 0.5, 1, 2, 4, 6, and 8 KHz. Tinnitus was induced by presenting a 60-second 1 KHz tone at 95 dB SPL. A white noise, a tone at the matched induced tinnitus frequency and a critical band noise centred at the matched induced tinnitus frequency were employed to mask induced tinnitus.

The average loudness match of ongoing tinnitus to noise was 15.0 dB SL and the average pitch match 5.5 KHz. Generally, the masking of tinnitus did not show similar pattern to masking of an external stimulus. Contralateral masking of tinnitus was possible in most cases. Subjects with hearing loss and those with normal threshold arrived at similar pitch match, loudness match and minimum sensation masking levels. The average maximum loudness match of induced tinnitus was 23.3 dB SL and the average pitch match was 5.1 KHz. Induced tinnitus lasted on average for 81.2 seconds and followed temporal characteristics similar to those obtained in previous studies. There was an initial growth of loudness to a steady level followed by an abrupt fall to a level below threshold. Masking of induced tinnitus with a white noise was as effective as with a tone at the matched induced tinnitus frequency and with a critical noiseband centred at the matched

induced tinnitus frequency. Contralateral masking was also possible for induced tinnitus.

Results show results that (1) subjective descriptions of ongoing and induced tinnitus are similar, (2) objective measures of pitch and loudness of ongoing and induced tinnitus are similar, (3) both the masking of ongoing and induced tinnitus did not follow the rules governing the masking of an external stimulus and could not be explained by the concept of critical band, and (4) contralateral masking of ongoing and induced tinnitus was possible in most cases. In view these results, it is concluded that (1) neither ongoing nor induced tinnitus are not processed like an external stimulus, (2) the generation of ongoing and induced tinnitus involved similar processes and that at least some forms of onging tinnitus, probably those associated with noise exposure or acoustic trauma, are temporary tinnitus made permanent, and (3) the study of temporarily induced tinnitus would provide more information on the pathological ongoing tinnitus.

CHAPTER ONE INTRODUCTION

In this chapter a discussion on some general issues on tinnitus is given. Masking of tinnitus is treated separately in one section because of its particular relevance to the present investigation. A section on the masking of external stimuli is included for comparison. Finally, some recent research findings on induced tinnitus are presented and discussed.

TINNITUS

What is tinnitus?

Tinnitus is usually referred to as the perception of sound in the absence of external stimulus (Moore 1982, Lutman and Haggard 1983). Such a definition embraces both subjective and objective tinnitus. Objective tinnitus has its acoustic source located in the head or neck region because of vasculature or masculature anomalities. Tinnitus is subjective when no acoustic source can be found responsible for the sound perception.

Perhaps the most exciting recent discovery related to tinnitus is that of spontaneous otoacoustic emissions which can be recorded in the ear canal by sensitive instruments and averaging techniques (Zurek 1981). Such emissions are generally thought to be related to the mechanical activity in the cochlea reflecting an active process with a strong non-linear component (Kemp 1979). For a time, this created high hopes that an objective acoustic basis had been found for 'subjective' tinnitus. However, attempts to equate acoustic emissions with tinnitus have at best shown that the tinnitus of only a very small percentage of sufferers can be attributable to acoustic emissions. Most tinnitus has different frequency characteristics to those of the emissions (Zurek 1981). Other differences between the emissions and tinnitus include the low annoyance associated with the emissions and the low awareness of the existence of the emission by the people who have it: spontaneous emissions are commonly observed objectively but only infrequently observed by the people who have it. Aspirin produces acute tinnitus accompanied by temporary hearing loss but suppresses otoacoustic emissions (McFadden and Plattsmier 1983). Furthermore, spontaneous emissions can be suppressed by external sound, and the pattern of suppression produced by sounds of different frequencies is remarkably similar to that of psychophysical tuning curves (Zurek 1981) indicating that spontaneous emission has a peripheral origin, is a product of the cochlea and that it behaves like an external stimulus. On the other hand the masking pattern of tinnitus does not follow the pattern seen in psychophysical tuning curves (Feldmann 1971) suggesting that tinnitus may have a different origin to otoacoustic emissions. Thus overall no acoustic or objective concommittant has been found for the tinnitus of most sufferers.

Epidemiology

A survey carried out by the British Institute of Hearing Research (Coles 1984a) indicates that about 35% of adults in the population have experienced tinnitus of some type at one time or another. About 15% of adults have spontaneous tinnitus which lasts longer than five minutes and about 0.5 to 1% of adults find their tinnitus having a debilitating effect on their quality of life. An interesting finding is that annoyance is not necessarily related to sleep disturbance. The dissociation between annoyance and insomnia has also been reported in a study where factor analysis was used to access the relationship between the various aspects of tinnitus annoyance and the loudness of tinnitus (Jakes, Hallam, Chambers and Hinchcliffe 1985). This suggests that insomnia may not be a good indicator of tinnitus severity and that tinnitus may not be a direct cause of sleep disturbance which has so often been reported as a related complaint. However, it is also possible that the population studied was different from the population of clinical patients usually encountered by doctors and specialists.

The IHR survey also showed that tinnitus prevalence increased with age and noise exposure and both factors were independent determinants for the risks of having tinnitus. The association of tinnitus with hearing threshold was also reported (Coles 1984b). In another study by Chung, Gannon and Keith (1984), it was found that when hearing loss was controlled, age, sex, noise exposure and smoking history ceased to be factors in determining the probability of tinnitus. Hearing threshold was the single most important factor in predicting tinnitus occurence. There was an exponential increase of tinnitus cases as hearing threshold increased. However, there still exists a small percentage of people who suffer from tinnitus but exhibit no measurable hearing loss.

Sometimes tinnitus is considered to be a psychological disorder and is treated accordingly. The psychosomatic approach assumes that it is the presence of a long-lasting pathological personality rather than that of some organic abnormality that causes the complaint of tinnitus. To evaluate this proposition, Gerber, Nehemkis, Charter and Jones (1985) investigated the psychological make-up of patients reporting intractable tinnitus. It was found that the severity of tinnitus was not related to the patients' hysterical or psychosomatic MMPI (Minneosota Multiphasic Personality Inventory) profile, locus of control, life satisfaction or occurrence of stressful life events. No psychopathological pattern can be distinguished to separate the tinnitus patients from others. Therefore, it was concluded that it is unwarranted to treat tinnitus as a psychosomatic disorder. Moreover, psychological treatments- e.g. cognitive intervention which alters the beliefs and attitudes of patients towards their tinnitus, relaxation training and treating other unrelated psychological problems- can only help reduce the distress and annoyance caused by tinnitus while the sensory aspects of tinnitus as measured by loudness match, loudness rating and masking level remain unaffected (Jakes, Hallam, Rachman and Hinchcliffe 1986, Hallam and Jakes 1985).

It appears that tinnitus does have an organic basis and can arouse undesirable psychological reactions like emotional distress and social withdrawal. This explains the findings of Reich and Johnson (1984) who, in an attempt to investigate the personality characteristics of tinnitus patients, found that tinnitus patients showed more social adjustment problems than the hearing loss group as measured by the MMPI 168. Although this result is consistent with the possibility that those people with certain personality problems are more liable to tinnitus, it seems more plausible that tinnitus has profound psychological effects on its sufferers causing stress, anxiety and withdrawal; hence a vicious cycle where tinnitus causes stress which in turn causes more severe tinnitus. In this context, the fact that tinnitus can become more severe when people are under stressful situations is a frequently reported clinical impression.

Loudness and Annoyance

Among all the unresolved problems concerning tinnitus, the discrepancy between the low apparent loudness of tinnitus when measured with matching techniques and the subjective reports of extreme loudness, distress and annoyance experienced seems most perplexing. A usual method of obtaining an objective measure of the perceived loudness of tinnitus is to determine the sensation level of an external sound the loudness of which is adjusted to match the loudness of the tinnitus. The test sound is introduced at the frequency which matches the pitch of the tinnitus. Loudness matching of tinnitus has generally produced very low mean sensation level (SL) values. Fowler (1942) used an external tone at the tinnitus frequency with which to match the loudness of tinnitus. The loudness of tinnitus was matched to a tone with sensation level of 5 to 10 decibels (dB). Recent findings agree well with Fowler's results (Meikle and Taylor-Walsh 1984, Man and Naggan 1981). The minimum masking level of tinnitus has also been employed as an objective measure of tinnitus loudness and annoyance. It is obtained by determining the lowest sensation level at which the tinnitus can be masked by an external stimulus. Generally a pure tone at the matched tinnitus frequency (see section on Pitch of Tinnitus below), a narrow band noise centred at the matched tinnitus freqeuncy, or a broadband noise is used. The underlying assumption is that the perceived severity of tinnitus is related to how easy or how difficult it can be rendered inaudible by the presence of external sounds. However, attempts to estimate the loudness of tinnitus by masking techniques have also failed to show uncontrollable could cultivate a sense of helplessness and have adverse effects on behaviour and emotion. The persistence of tinnitus also helps to make it aversive. Persistent sound even when it is soft, can be very irritating and cause greate annoyance. Most people have the experience of being very annoyed by dripping of water from a tap. Pitch matches of tinnitus have often shown that tinnitus associated with sensori-neural hearing loss (except for Menière's disease) lies at the high frequencies (Reed 1960, Graham and Newby 1962). As high frequency sounds are shown to be more annoying than low ones, people would find their high-frequency tinnitus particularly annoying. The meaning that tinnitus acquires can also cause concern and anxiety (Hallam and Jakes 1985). People may interpret their tinnitus as a symptom of serious illness or a threat to further hearing loss.

A more probable phenomenon which has been put forward to explain the low loudness matches of tinnitus is the phenomenon of loudness recruitment. Recruitment, which is a usual concommittant of sensori-neural hearing loss, refers to an abnormally rapid rate of growth of loudness with increasing intensity. This can best be demonstrated by comparing the loudness-intensity function of the normal ear to that of the damaged ear in the unilaterally deaf. Near threshold, stimuli presented to the two ears are matched in loudness when the stimulus in the damaged ear is raised by the amount of hearing loss. If, for example, the threshold of a 1 KHz tone is 0 dB sound pressure level (SPL) in the normal ear and 70 dB SPL in the damaged ear, then a 1 KHz tone of 70 dB SPL in the damaged ear would sound as loud as a 1 KHz tone of 0 dB SPL in the good ear. As stimulus level increases, the match occurs nearer and nearer to normal sound pressure levels. In this case, a tone of 100 dB SPL at the damaged ear would sound as loud as a tone of 100dB SPL at the good ear although the tone at the damaged ear is only 30 dB above threshold (i.e. 30 dB sensation level) while the tone in the good ear is 100 dB above threshold (i.e. 100 dB sensation level). So the steeper than normal loudness-intensity function in the damaged ear rendered the sensation level inadequate as a measure of loudness.

One of the explanation for recruitment depends on the assumption that there exist two populations of nerve fibres, a low threshold group innervating the outer hair cells and a high threshold group innervating the inner hair cells. If the outer hair cells which are susceptible to damage by noise exposure and ototoxic drugs were damaged then the activity of the low threshold fibres would be affected leading to an elevation of threshold. The inner hair cells however would remain intact and so the high threshold fibres would work normally; thus the activity in response to high sound levels would be normal; hence recruitment. However, it is now quite well established that about only 3% of the fibres innervate the outer hair cells. Salvi, Hamernik and Henderson (1983), in a study on the response patterns of auditory fibres, failed to find two populations of fibres with high and low threshold. In a review of single-fibre studies in the cochlear nerve, Evans (1975) also concluded that when sufficient data were gathered and the frequency response of the sound system corrected for, the threshold of the cochlear fibres was uniformly low.

Evans (1975) explained recruitment in terms of the broadened tuning curves and the elevated threshold of fibres that usually accompany outer hair cell damage after noise exposure and ototoxic drug treatment. If tuning curves are abnormally broad with shallow slopes and missing tips, then the rate at which activity spreads across the nerve fibres as stimulus intensity is raised will be greater than when the tuning curves are normal. If the sensation of loudness is related to the proportion of fibres active, then loudness would grow at a greater rate when the tuning of the fibres is broad than when it is normal and sharp.

Since tinnitus often occurs around the frequencies of hearing damage (Goldstein and Shulman 1981, Man and Naggan 1981) and people with sensori-neural hearing loss do have broadened tuning curves (Zwicker and Schorn 1978), a recruitment-like mechanism is very likely and would render the loudness of tinnitus equivalent to the loudness of the comparison sound with a corresponding sound pressure level rather than the sensation level(SL) which is a commonly adopted unit in tinnitus loudness matching. Therefore, sensation level cannot adequately reveal the subjective sensation of loudness in the hearing damaged. By asking the patients to do a loudness match of their tinnitus with a tone with a frequency located at the non-tinnitus normal hearing portion of the audiogram and comparing the results thus obtained to the loudness match measure arrived at by using the traditional method where the frequency of the comparison tone was set at the tinnitus frequency, Vernon and Fenwick (1984) concluded that there were at least some patients showing recruitment. This group of patients reported high sensation levels when loudness matching was carried out at the normal low frequency range but the level of the match gradually decreased as the comparison tone approached the frequency of the tinnitus. Recruitment may account for the significantly higher mean sensation level obtained when loudness match was carried out with a comparison tone set at a frequency with normal hearing threshold in Johnson and Goodwin's study (1981): An average of 23.9 dB SL was obtained as opposed to an average of 6.6 dB SL when the traditional method was used.

Jakes, Hallam, Chambers and Hinchcliff (1986a) suggested that measurement errors attributable to poor self-report scales and subjects not understanding the procedure could contaminate the result and account for the usually obtained low correlation between the loudness match and the subjective reports of loudness. When subjects having difficulty with the procedure were excluded from analysis, a high correlation of 0.87 was found between a 5-point adjectival scale (the point being laballed 'extremely loud', 'loud', 'moderate', 'quiet' and 'extremely quiet') and the matched loudness in personal loudness units (PLU). The PLUs were transformed from the the loudness match at 1 KHz and the subject's individual loudness function. The subject's most comfortable loudness level (MCLL) at 1 KHz and loudness level judged to be half and twice as loud as the MCLL were measured. The individual loudness function was then derived based on the growth of loudness from half of the MCLL to either the MCLL or twice the MCLL. The high correlation obtained in using PLUs is no surprise since the measure takes into account the subjective response to sound intensity. In addition, the frequency of the tone used for loudness matching was located within the normal hearing range of most patients, and little recruitment would hence be anticipated.

Pitch of Tinnitus

That tinnitus may have different spectral characteristics is evident in the descriptions people use to describe their tinnitus. Hissing, ringing/whistle, ocean roar, steam whistle, tone, hum and crickets are some of the most frequently encountered qualitative descriptions (Goldstein and Shulman 1981). Attempts to obtain more objective characterisation than that provided by verbal reports can be dated back to 1903 when Spaulding (cited in Stephens 1984) tried to match the pitch of the tinnitus of his patients by playing different notes on his violin. Hazell (1981) made use of a music synthesizer and adjusted it according to his patients' instructions until the closest possible match was achieved. The waveforms obtained were not simple. They typically consisted of one or more relatively narrow bands with one or more pure tones imposed upon them.

Today the pitch of tinnitus is usually estimated by determinig the frequency of an external sound the pitch of which matches best the pitch of the tinnitus. The test sound is presented to the subject at the same estimated loudness level of the tinnitus. One interesting aspect of the pitch of tinnitus is its relation to the underlying pathology. Studies have been made to relate the frequency of tinnitus to underlying pathology. Generally subjects with conductive hearing loss have low frequency tinnitus (about 120 to 1400 Hz) while tinnitus accompanied by acoustic trauma is perceived at higher frequencies (Reed 1960, Graham and Newby 1962, Man and Naggan 1981). Patients with Menière's syndrome also exhibit tinnitus at a significantly lower frequency than those with other sensori-neural hearing loss (Nodar and Graham 1965). In a study of the masking pattern of tinnitus in about 200 patients, Feldmann (1971) also noted the association between high-pitched tinnitus and industrial hearing loss. The pitch of tinnitus in the normal hearing people, on the other hand, is localized at the low frequency range (Cahani, Paul and Shadar 1983). The different frequency characteristics may suggest different processes involved in the generation of tinnitus in people with and without cochlear damage.

Another purpose of identifying tinnitus frequency is to assign an 'appropriate' masker to mask tinnitus. The use of masking has been taken up seriously as a treatment to provide relief to tinnitus sufferers. Usually the masking noise employed contains the frequency matched to the pitch of the tinnitus (Vernon 1981, Johnson and Fenwick 1981). However, the use of a masker centred at the tinnitus frequency is questionable as it has been shown repeatedly that the masking of tinnitus is very unlike that of an external sound, and a masker with a frequency well away from that of the tinnitus can often be as effective as one centred at the tinnitus frequency (e.g. Penner 1987, Burns 1984).

MASKING OF EXTERNAL STIMULI

The Masking Pattern

Before going into the masking of tinnitus, a brief discussion on the masking of one external sound by another is given here so that a comparison between the two can be made. Masking is usually defined as 'the process by which the threshold of audibility of one sound is raised by the presence of another ' (ASA 1960). The study of masking has a long history. In classical masking experiments, the masker is kept constant in sound pressure level and frequency and the threshold of the masked sound is measured as a function of its frequency. Apart from being useful in practical situation, a knowledge of the physical parameters affecting the masking of one sound by another can give us information on how our auditory system analyses different sounds in our generally noisy environment.

Wegal and Lane (1924) published the first systematic investigation on the masking of one pure tone by another. Later investigations usually employed narrow band noise rather than tones as maskers to avoid the complications of beats and combination tones which occur when the pure tone masker and masked tone are close in frequency to each other. The tonal and noise band studies have arrived at basic agreement concerning the pattern of masking.

It is found that the greatest amount of masking occurs when the masker and the masked sound are close in frequency and decreases as the masked sound moves away from the (centre) frequency of the masker. As expected, the amount of masking increases with the level of the masker. At low masker levels (below 40 dBSPL), the masking curve is symmetric around the masker frequency. It becomes asymmetrical and wider as the masker level is raised, with more masking above than below the masker frequency. At high masker levels (above 80 dB) the asymmetry is quite marked. This phenomenon is called the 'upward spread of masking'. Masking curves are relatively wide for low frequency maskers as compared to high frequency maskers; that is, low frequency maskers are effective over a wider range of frequencies than high frequency maskers are. Lastly, the amount of masking and the effective masker level are linearly related and this linear relationship is independent of frequency. Thus overall the amount of noise necessary to mask a signal is roughly predictable when the physical parameters of the stimuli are known.(Hawkins and Stevens 1950, Bilger and Hirsh 1956).

The Concept of Critical Band

The masking pattern is best explained by the concept of auditory filter proposed by Fletcher (1940). He postulated that the peripheral auditory system operates as if it contained a bank of bandpass filters. In detecting a signal, the filter with a centre frequency close to that of the signal is in operation. Only a narrow band of frequencies passing through that filter contributes to masking and the narrow band of frequencies is referred to as the 'critical band'. That a narrow band is responsible for masking has been suggested in numerous studies (e.g. Greenwood, 1961). Since then many attempts have been made to estimate the width of a critical band and the shape of the auditory filter. Different psychophysical methods like notched-noise masking (Patterson 1976), two-tone masking (reviewed by Scharf 1961) and loudness summation measure (Zwicker, Flottorp and Stevens 1957) have been used. One which is of relevance to the present study is masking in which the frequency and the level of the masked sound is fixed. Usually a test sound at a very low level of 10 dB SPL is used in order to produce activity in a restricted frequency area. The level of the masker needed to just mask the test tone is determined at different masker frequencies. Masking curves thus obtained are called psychophysical tuning curves because of their having similar characteristics to the neural tuning curves (Small 1959). This type of masking is more comparable to the masking of tinnitus since tinnitus is the sound to be masked and maskers of different frequencies and levels are used to mask the tinnitus.

Psychophysical tuning curves are thought to be better tools than the classical masking curves for studying the filter characteristics of the ear since fixing the masked sound at a particular frequency discourages the use of a different filter every time the frequency of the masked sound is changed as is the case with the traditional masking paradigm. In that case, the masking audiogram reflects activities of a group of filters rather than a single one. As the shape of the psychophysical tuning curves bears a close resemblance to that of the neural tuning curves and the critical bandwidth measures in man correspond quite well over a wide range of frequencies with the analogous measure for individual cat cochlear fibres (Evans and Wilson 1973), it appears that the critical band property of the ear derives directly from the frequency selectivity of the cochlear fibres and is therefore already established at the level of the auditory nerve. This also serves to account for the asymmetry of the masking curve as the neural tuning curve of an auditory fibre is steeper on the high frequency side than on the low frequency side. That is why masking has always been considered to be mostly a peripheral phenomenon.

Forward Masking

Threshold shifts can occur when the masker is presented after the masker is terminated. This type of masking is called forward masking. The duration of forward masking is usually limited to a few hundred milliseconds after the cessation of the masker. The amount of forward masking is affected by the duration of the masker. More forward masking is found for longer masker duration. Forward masking exhibits a frequency-dependent relationship not unlike that of simultaneous masking and is consistent with measures of recovery of electrophysiological function of the eighth nerve indicating that it is largely a peripheral receptor phenomenon. It is explained either in terms of a persistence of neural activity evoked by the masker or in terms of a reduction in the sensitivity of the previously stimulated cells.

Apparently comparable to forward masking is a phenomenon called residual inhibition which very often occurs in the masking of tinnitus. Tinnitus can often be 'masked' after masker offset. The differences between forward masking and residual inhibition are discussed in a later section.

Central Masking

Another type of masking which is relevant to the discussion of the masking of tinnitus is central masking. Central masking is defined as the 'threshold elevation of a test sound presented to one ear in the presence of a masking sound in the contralateral ear when a direct acoustic interaction between the two is precluded' (Zwislocki, 1973 p.788). The magnitude of central masking shows considerable individual differences and is far less than that observed in monaural masking. It is greatest at stimulus onset and decays to a steady-state level at about 160 msec (Zwislocki, Damianopoulos, Buining and Glantz 1967, Zwislocki, Buining and Glantz 1968). The amount of central masking also depends on the temporal presentation of the masker and the signal with the greatest effect when the masked sound and masker are pulsed on and off together, a much lesser effect when both are continuous and the least effect when the masker is continuous and the masked sound pulsed (Dirks and Norris 1966). For brief delays between masker and signal onset, central masking is frequency dependent. More central masking occurs with high frequency maskers than low frequency maskers. When the signal is at or close to the frequency of the masker, the maximum threshold shift is observed, forming a peak with a width consistent with the critical bandwidth (Zwislocki 1973). The central masking curve is symmetrical with respect to the frequency of the masker; and at the edges of the peak, it drops rapidly. Depending on the nature of the masker, a shallow minimum at each side of the peak or several local minima can be found. For long delays (greater than 160 msec) between masker and signal onset, the masking curve is flat (Zwislocki et al 1968).

The complexity of the central masking curve points to the complexity of the process involved. Since a direct acoustic interference of the two sounds presented to the two ears is eliminated as an explanation for the threshold shift, central masking is thought to involve neural interaction at or beyond the point where inputs from two ears are combined, generally believed to be at the level of the superior olivary complex where bilateral representation is available (Zwislocki 1973).

MASKING OF TINNITUS

Masking sounds have been known to affect tinnitus for many years. In tracing the history of the masking of tinnitus, Vernon (1981) credited the first report of masking of tinnitus to Hippocrates in 400 BC. More than 2000 years later, Spaulding (cited in Stephens 1984) estimated the pitch of his patients' tinnitus by playing different notes on his violin and then attempted to mask the tinnitus by producing a tone of the same pitch selected by his patients. Wegal (1931) claimed that he could mask his own tonal tinnitus with tones of different frequencies. Depending on the different masking results of his patients, Fowler (1940) divided tinnitus sufferers into three groups-- those whose tinnitus could be easily masked, those whose tinnitus could only be masked at high masker level and those whose tinnitus was resistant to masking. However, unlike the masking of an external tone where the level of the masker is dependent on the level of the signal the ease with which tinnitus could be masked is not related to the estimated loudness of tinnitus (Fowler 1941, Mitchell 1983).

Tinnitus Masking as Compared to Masking of an External Stimulus

One frequently quoted study concerning tinnitus masking was carried out by Feldmann (1971). In this study, tinnitus pitches were identified and masking of tinnitus were carried out in 200 patients. Broadband noise, pure tones and 1/3 octave band noise were used as maskers. The resultant masking curves were analysed in relation to the pure-tone threshold audiograms of the patients and five different types of tinnitus masking patterns were arrived at.

Apart from frequency-specificity differences, there are other differences between tinnitus masking and the masking of an external stimulus which further highlight possible differences in the processes involved in the two kinds of masking. While an external tone can be masked quite easily by a broadband noise, there are some cases, although rare, of tinnitus which cannot be masked (Fowler 1940, Feldmann 1971). Usually a tone does not easily mask an external broadband noise but a tone can easily mask the broadband tinnitus of patients with Menière's disease. People with Menière's disease often describe their tinnitus as a low roaring noise. Unlike the case in ordinary masking, the level of noise necessary to mask tinnitus is unpredictable; it varies from threshold to extremely high levels. Although with some tonal tinnitus masking is most effective in the frequency range near the tinnitus frequency, frequencies higher than the pitch of the tinnitus are more effective than frequencies lower than the pitch of the tinnitus-- a reversal of the frequency-specific relationship of ordinary masking (Feldmann 1981). The concept of the critical band has been applied to the masking of an external sound quite satisfactorily: as masker bandwidth increases, the level required to mask a tone signal remains constant up to some critical bandwidth beyond which further increases in masker band width require an increase in masker level. This does not apply to tinnitus masking. The width of the masker does not determine the effectiveness of the masking of tinnitus (Johnson and Mitchell 1984). Contralateral masking of tinnitus is sometimes as effective as ipsilateral masking and this occurs at an intensity where bone conduction cannot be a satisfactory explanation (Tyler, Babin and

Niebuhr 1984). Residual inhibition, defined as the disappearance of tinnitus after the cessation of the masker, can occur for up to 1800 msec., much longer than can be observed from forward masking (Feldmann 1971). The length of residual inhibition depends on the intensity and duration of the masker, with duration having a much stronger effect (Tyler et al 1984).

These disparities between tinnitus masking and ordinary masking, particularly the phenomenon of contralateral masking, have led many researchers to the suggestion that tinnitus masking involves processes different from that of the masking of an external stimulus which presumably involves the physical interaction of the stimuli along the cochlear partiction at the peripheral level. Feldmann (1971) postulated tinnitus masking to be a phenomenon related to neural inhibition, some kind of lateral inhibition which spreads from the region activated by the masker and suppresses the abnormal spontaneous activity which presumably is responsible for the generation of tinnitus.

INDUCED TINNITUS

A tinnitus-like sensation can also be induced temporarily after acoustic stimulation. In an experiment carried out to investigate the phenomenon of auditory fatigue, Ewing and Littler (1953) reported that subjects experienced a 'rushing sound' in the stimulated ear during the first two minutes after cessation of the fatiguing tone. Temporal threshold shift persisted after the disappearance of induced tinnitus. 'A loud roaring' tinnitus was also reported by Hirsh and Ward (1952) following exposure to a 0.5 kHz tone at 120 dB SPL. The noisy tinnitus died at about 70-80 seconds just as threshold began to rise.

There have been very few investigations conducted with the purpose of studying the various characteristics of tinnitus which is temporarily induced. One of these was reported by Loeb and Smith (1967). With a view to studying the relationship of the characteristics of induced tinnitus, those of the inducing stimulus, and those of temporary threshold shift, tinnitus was induced deliberately by using eight different stimuli as inducers or fatiguing agents. They were 0.5, 1, 2 and 3 KHz tones, a white noise and 1.2 - 2.4, 2.4 -2.8 and 6 -12 KHz noise bands. The initial level of the fatiguing stimuli was set at 90 dB SPL. However, subjects were run repetitively with each stimulus until either a temporary threshold shift of 40 dB was obtained or until a stimulus level of 120 dB was reached. Subjects performed a pitch match to their induced sensation by adjusting the frequency of a tone delivered to the contralateral ear.

Contrary to earlier findings, the induced tinnitus reported in this study was tonal rather than noisy in nature. Although the way the data was collected did not allow statistical analysis, the authors concluded that induced tinnitus frequency did not coincide with the frequency of maximum threshold shift and that it increases as stimulus frequency increased. A point which is worth noting in this study is the reliability of subjects in identifying pitch matches for their induced sensation. At the highest stimulus level condition, subjects were run twice and the test-retest co-efficient showed that subjects were fairly reliable in these pitch matches although inter-subject variability was great.

A similar study was carried out by Atherley, Hempstock and Noble (1968) to test the hypothesis that noise induced temporary tinnitus and temporary threshold shift had a common origin. The stimuli used in this study were 1/3-octave band noise centred at 2, 3, 4 and 6 KHz. The level and duration of exposure was 110dB SPL and 5 minutes respecticely. A pitch and loudness match was carried out in the contralateral ear immediately after exposure where the level and frequency of a comparison tone was adjusted by the experimenter according to subjects' instructions. Threshold was determined about two minutes after stimulus termination. It was found that 89% of the subjects developed induced tinnitus as a result of the exposure. The median loudness in sensation level was 9 dB. In agreement with the findings of Loeb and Smith (1967) the induced tinnitus reported had a definite tonal quality and the frequency of induced tinnitus increased as stimulus frequency increased. Moreover, the frequency of induced tinnitus was always lower than the frequency of maximum threshold shift. The difference in frequency between the two corresponded to a constant distance on the basilar membrane, the width of a critical band. In both of these studies, especially the one by Loeb and Smith, the level of the stimuli used was unusually high and duration quite long. Both studies revealed considerable inter-subject variability.

While it appears that the frequency of induced tinnitus is affected by the frequency of the inducing stimulus, the loudness of the induced tinnitus is affected by stimulus intensity. It increases with the level of the stimulus. Plaisted (1985) studied the effects of inducing tone level, frequency and duration on the loudness of tinnitus. Subjects were exposed to tones of different levels, frequencies and duration. Immediately after cessation of the inducing tone, a dichotic loudness matching task was carried out. This was achieved by subjects' adjusting the level of a white noise delivered to the contralateral ear so that the white noise sounded as loud as the induced sensation in the opposite ear. Matches of 4 dB SL and 10-15 dB SL were reported for the 85-90 dB SPL and 95-105 dB SPL inducing tones respectively. On the other hand, tinnitus loudness was independent of stimulus frequency and duration.

Contrary to the findings of Loeb and Smith (1967) and Atherley et al (1968), recent studies on induced tinnitus reported internal sound sensation of a noisy rather than tonal nature (Kemp and Plaisted 1986).

Induced tinnitus seems to follow a specific temporal pattern. There is usually an initial period of growth in loudness followed by a slow growth before it dies away rather abruptly. The induced tinnitus usually lasts for 80 to 90 seconds and it can be lengthened by increasing the frequency of the inducing tone (Kemp and Plaisted 1986).

Aim of the study

The aim of the present study is to investigate the various aspects of ongoing and induced tinnitus to see whether the characteristics and behaviour of short-term experimentally induced tinnitus bear any resemblance to those of the pathological ongoing tinnitus.

The experiment is designed to obtain the following information on induced and ongoing tinnitus: subjective descriptions, severity ratings, loudness matching measures, pitch matching measures and minimum masking levels.

Since most studies in the literature of tinnitus are set in a clinical environment and so dealt mainly with people with hearing loss, special effort is made here to recruit tinnitus sufferers with normal hearing threshold.

In the following chapters, the short term experimentally induced tinnitus is, for brevity, referred to as 'induced tinnitus' and the permanent ongoing tinnitus is referred to as 'tinnitus'.

CHAPTER TWO METHOD

APPARATUS

Hearing thresholds of all subjects were measured and recorded by a Grason Stadler 1703B recording audiometer.

White noise for the measurement of noise threshold, loudness matching and masking levels was produced by a Lafayette noise generator. All the pure tones except for the tone maskers of induced tinnitus employed in the second part of the experiment were produced by an Interstate Electronics Corporation (IEC) F55A function generator. A Trio frequency counter was employed to monitor the frequency of the pure tones. Pure tone maskers of induced tinnitus were generated by another IEC fuction generator (F34). Noisebands for the masking of induced tinnitus was produced by the Lafayette noise generator feeding into a variable filter (Kemo VBF8) with 90dB/octave cutoffs.

The 1 KHz inducing tone was fed directly to one ear of a set of TDH 50P Headphones via a manual switch. All the other sound stimuli were fed into the audiometer, the output of which was further attenuated by a Marconi variable attenuator (TF338C) before finally being fed into one or other ear of the headphones. Thus the level of these stimuli (except for the tones for frequency matching, see below) could be controlled by the subject using the remote control mechanism provided by the audiometer. The level of the stimuli was traced automatically by the audiometer chart recorder. When the audiometer was used in this way its own tone production was bypassed.

The level of all the stimuli was calibrated at the earphone using a precision sound level meter (Bruel & Kjaer Type 2235) connected to an artificial ear (Bruel & Kjaer Type 4152).

SUBJECTS

A total of 20 subjects, 16 males and 4 females, with their age ranging from 18 to 60 (average 38.2) participated in the experiment.

Sixteen subjects, subjects 1 to 16, took part in the first part of the experiment which was concerned with the masking of tinnitus. They volunteered as subjects in response to an advertisement inserted in the "Chronicle" and "Canty" of the University of Canterbury. Thirteen of them were male and three of them female. Their ages ranged from 18 to 60 with an average of 40.8 years. Among the 16 subjects, 11 of them had hearing impairment, 9 showing high frequency hearing loss typical of sensori-neural deafness. The average age for the hearing loss subjects was 47.4 years with a range of 25 to 60. Five of the subjects in this group, subjects 12 to 16, had thresholds in the normal hearing range and were aged from 18 to 42 with an average age of 26.4 years.

Seven subjects, subjects 14 to 20 took part in the second part of the experiment which was concerned with the masking of induced tinnitus. Six were males and one was female. The age of this group ranged from 19 to 35 and averaged 24 years. All the subjects in this part of the experiment had hearing thresholds in the normal range. Three of them, subjects 14, 15 and 16 suffered from tinnitus and had also served as subjects in the first part of the experiment. The other four subjects did not usually experience tinnitus.

Subjects are considered to have normal hearing if their thresholds at all the freauencies tested (0.5, 1, 2, 4, 6 and 8 KHz) lay below 20 dB hearing level (HL).

PROCEDURE

Part One

The experiment was divided into two parts. The first part of the experiment investigated the masking of tinnitus. At the beginning of each experimental session, the hearing threshold of subjects were measured by using the audiometer. Pulsed pure tones at 0.5, 1, 2, 3, 4, 6 and 8 KHz were presented in succession first to the left then to the right ear and subjects responded by either depressing or releasing the switch on the remote control trigger connected to the audiometer. When the trigger was depressed, the level of the tone decreased automatically at 2.5 dB/sec and increased at 2.5 dB/sec if released. Subjects were instructed to depress the switch on the control as soon as a tone became audible and release it as soon as it became inaudible so that the tone was maintained at a level that could be just heard. The same remote control device was employed for loudness matching and masking tasks to adjust the level of the stimuli. The response of the subjects were recorded by the automatic recording device of the audiometer. Pulsed noise threshold for both ears were measured in the same way.

After the thresholds were measured, a steady noise was presented to the contralateral ear of the subject and a dichotic loudness match of tinnitus to the noise was carried out. Subjects adjusted the level of the noise constantly by using the remote control trigger so that the loudness of the noise matched the loudness of tinnitus. They were warned beforehand that the noise might sound quite different from their tinnitus and that they had to try their best to compare the loudness of the noise to that of their tinnitus disregarding the other qualities of the sound. Ipsilateral ear was defined as the ear having the tinnitus if tinnitus was unilateral, as the ear with the louder tinnitus for most of the time if tinnitus was bilateral. If a subject had almost the same level of tinnitus in both ears then the ipsilateral ear was the ear of the subject's choice.

A pitch match of tinnitus to an external tone was also carried out at the contralateral ear to determine the tinnitus frequency. A tone was run from the low to high frequencies once to give the subject an idea of the range of the frequencies, then as the tone was turned from the high to low frequencies slowly, the subject gave instructions to the experimenter and the experimenter adjusted the frequency of the tone accordingly until a closest possible match to the pitch of the tinnitus was achieved. To guard against octave confusion, a tone with the chosen frequency and a tone with a frequency an octave below the chosen one were presented and subjects were asked to pick the one which better matched the pitch of their tinnitus. The frequency finally chosen was taken as the tinnitus frequency. Once again subjects were reminded beforehand that they were required to concentrate on comparing the pitch and not the other qualities of the tone and the tinnitus. A loudness match of tinnitus to a tone at tinnitus frequency was conducted afterwards in a way similar to the loudness match to noise.

Masking of tinnitus were carried out at both ears. A steady white noise was presented first. Then tones of 0.5, 1, 2, 4, 6, 8 KHz and at tinnitus frequency were presented at a random order. Subjects adjusted the loudness of the maskers through the same remote control trigger to a level that just masked their tinnitus. Thus they had to depress the switch once their tinnitus was masked by the stimulus and release it once they could hear their tinnitus again. The highest masker level that could be reached was set at 90 dB SPL. Stimuli for threshold measurements, loudness matches and masking all had a duration of 30 seconds.

Subjects attended three sessions on different days. Thresholds of tinnitus frequencies were measured at least twice at different times after the three sessions were over or during the sessions before exposure to any masking stimulus. A questionnaire was given to subjects at the first session to obtain some general information and subjective measure of severity of their tinnitus. A copy of the questionnaire is included in the appendix.

Part Two

The second part of the experiment investigated induced tinnitus and was only carried with subjects with normal thresholds. The inducing stimulus was a 1 KHz tone at 95 dB SPL with a duration of 60 seconds. It was delivered to the tinnitus ear or to the ear of the subjects' choice if the subject did not usually experience tinnitus. Immediately after the inducing tone was switched off, one of the following tasks was performed at each session.

(1) A steady noise was presented to the contralateral ear upon termination of the inducing tone and a dichotic loudness match was performed to trace the loudness of induced tinnitus. A maximum of 4 minutes duration was allowed by the recording device of the audiometer. After the loudness matching task was completed, usually when the induced sensation had already ceased, a pitch matching was carried out. The loudness matching and pitch matching followed the same procedure of loudness matching and pitch matching of tinnitus as described in the first part of the experiment. The only difference was that the loudness matching in part two was carried out for as long as the induced sensation lasted or for a maximum of about 4 minutes.

(2) Subjects also performed masking of their induced tinnitus in different sessions in a fashion similar to that described in part one of the experiment. The masking stimuli included white noise, a tone set at tinnitus frequency and a noise band of a critical band width centred at the tinnitus frequency. While masking with tones and noise bands was carried out at the

ipsilateral ear only, masking with noise was conducted in both ears. Masking of induced tinnitus was also carried out for as long as the induced sensation lasted or for a maximum of about 4 minutes as allowed by the recording device of the audiometer.

Subjects ran two trials for each task and trials where subjects had expressed doubt and difficulty were discarded and run again so a total of at least 10 sessions were carried out on each subject. Noise thresholds were also obtained at 5 different times before exposure to the inducing tone. Hearing tests were administered at and in between the first and last session to check for any hearing deterioration in the course of the experiment as a safety measure. Subjects also filled in a questionnaire at the end of the last session. Information on the loudness, annoyance and various other characteristics of induced tinnitus were obtained. (Refer to the appendix for a copy of the questionnaire.)

Both parts of the experiment were conducted with the subject seated in a sound attenuating chamber while the experimenter and the equipment remained outside.

At the beginning of the experiment, attempts were made to induce tinnitus on three subjects with tinnitus and hearing loss. The induced tinnitus of subject 3 only lasted for 2 or 3 seconds and so it was impossible to carry out any masking or loudness matching to it. His induced tinnitus was reported to be tonal and had a pitch match of around 550 Hz. Subject 5 reported having a noisy intermittent induced sensation with a pitch match of 200 Hz and lasting for 4 minutes. Subject 9 had a continuous tonal tinnitus at around 850 Hz and a loudness match to noise of 35.5 dB SL. However, both subjects 5 and 9 reported a worsening of their tinnitus after the induced tinnitus session. Although it was not clear whether the perceived worsening of their tinnitus was due to exposure to the inducing tone or to the heightened awareness of the subjects to their tinnitus or to the onset of a stressful event as was reported by subject 5, it was decided that the induced tinnitus part of the experiment should only be carried out on subjects with hearing threshols which lay within the normal limits.

CHAPTER THREE RESULTS

In this chapter, the results of the experiment are presented in three parts. Part one gives the results from the first part of the experiment including results in loudness matching, pitch matching and masking of tinnitus. Results on loudness matching, pitch matching and masking of induced tinnitus are given in part two. Part three comprises comparisons between the results of the first part of the experiment and those obtained from the second part of the experiment.

Part One: Results on Tinnitus

In the first part of the experiment, the first session was treated as a training session because many subjects experienced difficulty performing the tasks. Only tone thresholds and noise thresholds were averaged over all sessions; masking, loudness matches and pitch matches were averaged over the experimental (second and third) sessions only.

Subjects participating in this part of the experiment were divided into two groups according to their hearing thresholds. Those with hearing loss are referred to as the 'hearing-loss subjects' and those with hearing thresholds lying within the 20dB HL limit (see above) are referred to as the 'no-hearing-loss subjects'. Subjects 1 to 11 had hearing loss while subjects 12 to 16 had no hearing loss.

Figure 1 is an example of the ipsilateral masking results of a subject in one session as they appeared on the audiometer chart. Each interval on the chart represents a masking stimulus of 30-second duration. The tracing in each column indicates the level of the masking stimulus in sound pressure level adjusted by the subject to 'just mask' his tinnitus. Each interval was divided into two 15-second 'epochs'. The levels of the stimulus in sound pressure level in the two epochs were measured and averaged to give the masking level with one masker frequency in one session. Values thus obtained were then averaged over the two experimental sessions of a subject to give the masking level of tinnitus at one frequency. Results of loudness matching and threshold measurements were treated in a similar manner.

Subjective Reports

Subjective information on various characteristics of tinnitus was obtained from subjects by means of a questionnaire. Subjects had had tinnitus from a period of 5 months to 50 years. Eleven subjects reported tinnitus in both ears; four reported it in one ear and one in the head. Fourteen subjects reported their tinnitus to be a single sound sensation and two reported it to comprise two sounds.

Although no wide fluctuation in either the pitch or the loudness of tinnitus was reported, its pitch appeared less variable than its loudness. While ten subjects reported their tinnitus pitch to be 'constant and unchanging', thirteen found their tinnitus loudness to be 'generally constant but fluctuating at times'. Only one subject had intermittent tinnitus; the others had continuous tinnitus, probably because only people with almost constant tinnitus were invited to participate in the experiment. That most tinnitus had a tonal quality was reflected in the expressions subjects chose to describe it: six described their tinnitus as tonal, five described it as ringing and four as whistling.

Whether tinnitus was associated with noise exposure or acoustic trauma was less clear. Less than half of the subjects (6) had a history of noise exposure (defined as having been in a noisy environment where people had to shout in order to be heard for a period of at least six months). Seven subjects identified either noise exposure or acoustic trauma as events which initiated their tinnitus. Five subjects had neither noise exposure history nor acoustic trauma of any kind.

Subjective Measures of Tinnitus Severity

Loudness ratings, annoyance ratings, sleep disturbance, and tinnitus effects on the quality of life were employed as indices of tinnitus severity. They were measured on five-point scales accompanied by descriptive phrases at each point. Loudness of tinnitus was rated from 1, extremely soft, to 5, extremely loud. Annoyance was rated from 1, not annoying at all, to 5, severely annoying. Sleep disturbance caused by tinnitus was rated from 1, not disturbed at all, to 5, disturbed to an intolerable degree. Tinnitus effect on the quality of life was rated from 1, not at all affected, to 5, having a totally debilitating effect. Table 1 gives the frequency distributions on these subjective measures. As shown in Table 1, none of the subjects chose the highest point on the scale for any of the four different ratings of tinnitus severity. Overall although some subjects found their tinnitus quite annoying, it had very little effect on sleep or the quality of life. T-tests carried out between the group of hearing-loss subjects and the group of no-hearing-loss subjects on the four subjective ratings showed no significant ($p<0.05$) differences in mean rating. All statistics quoted in this and the following chapter are at 0.05 significant level.

Table 2(a) shows the correlation matrix of all the subjective severity measures. Annoyance, loudness ratings and quality of life measures were very highly correlated but sleep disturbance showed much weaker and even insignificant correlation with the other variables. This suggests that sleep disturbance might not be a major factor in tinnitus-related annoyance. Jakes et al (1985) also found that insomnia was not associated with any tinnitus related complaint.Correlations obtained from the group with hearing loss (refer to Table 2(b)) confirmed that sleep disturbance was not a good indicator of tinnitus severity. However, a different picture emerged when correlations of the no-hearing-loss group were examined. Table 2(c) gives the correlation matrix among all subjective measures of severity for the no-hearing-loss group. Annoyance rating still remained a strong index of tinnitus severity, correlating highly with all other measures. But unlike the results for the hearing-loss group, sleep disturbance turned out to be highly correlated with all other subjective severity ratings.

Pitch Match of Tinnitus

Ten subjects had different pitch matches in the two experimental sessions despite six of them reporting that their tinnitus pitch was constant and unchanging. This result might, of course, be due to a real change in tinnitus pitch over time, but it might also arise from subjects' inability to assign an exact match to the pitch of their tinnitus. Many subjects commented on the difficulty of the task because of the difference in quality between the test tone and their tinnitus. It is also possible that the different pitch matches arrived at in the two sessions arose because their tinnitus contained more than one single pitch sensation. The frequency of the test tone might have been adjusted to match the pitch of a different component of the tinnitus in each session. Two subjects, subjects 8 and 2 perceived their tinnitus as comprising two sounds. Five subjects matched the pitch of their tinnitus to tones of the same frequency in the two sessions and four of them reported that their tinnitus pitch was constant and unchanging. The average of the matches in two sessions was taken as the matched tinnitus frequency of the subject.

The matched tinnitus frequency of subjects ranged from 1950 to 9050 Hz. Eleven of the sixteen subjects matched their tinnitus to tones over 4 kHz. There appeared no obvious difference between the hearing-loss and the no-hearing-loss subjects. The hearing-loss subjects had matches between 3300 to 8000 Hz; the mean frequency match for this group was 5.4 kHz. The no-hearing-loss subjects had matches between 1950 to 9050 Hz, and a mean frequency match of 5.7 kHz.

Loudness Matches

Tinnitus was matched in loudness contralaterally to both a white noise and a tone of the matched tinnitus frequency arrived at in that session. Table 3 shows the mean loudness matching levels for the whole group and the groups with and without hearing loss. The sensation level of loudness matches was calculated relative to the contralateral noise and tone thresholds of the subject. The only exception was subject 5, whose loudness match to a tone at the matched tinnitus frequency was carried out ipsilaterally as his contralateral threshold of the comparison tone was above 90 dB SPL, i.e., above the maximum level that was reached by the tone.

There were no significant differences in loudness matches between the hearing-loss and no-hearing-loss group in loudness matches when the matches were expressed in sensation level.

A comparison between the means of loudness match to noise (SL) and loudness match to a tone at the matched tinnitus frequency (SL) showed no significant difference for the whole group, the hearing-loss group or the no-hearing-loss group. This result came as a surprise. Since most subjects showed hearing loss at high frequencies (at and above 4 kHz) and most subjects matched the pitch of their tinnitus to tones above 4 kHz, loudness recruitment was expected to affect loudness matching to a tone at the matched tinnitus frequency, thus producing tonal SLs that would underestimate the loudness of tinnitus. As white noise has equal energy at all frequencies, recruitment at high frequencies should have less effect on loudness matches when noise is used as the comparison sound. Therefore, loudness match to noise (SL) should be a relatively good measure of tinnitus loudness, and one would expect lower loudness matches in sensation level for the comparison tone as a result of recruitment. However, this did not occur. In fact, the mean loudness match to a tone at the matched tinnitus frequency (SL) was actually slightly higher than the mean loudness match to noise (SL) for the hearing loss group and the whole group.

Correlations between subjective severity ratings and loudness matches are given in Table 4(a-c). Table 4(c) gives the results for the no-hearing loss group. Despite the small number of cases in this group, loudness match to a tone at the matched tinnitus frequency in sound pressure level was significantly correlated with three of the subjective measures of tinnitus severity and loudness match to a tone at the matched tinnitus frequency in sensation level was also correlated with two subjective severity indices. However, none of the subjective ratings were correlated with the more objective measures of loudness in the hearing-loss group. (Refer to Table 4(b).) This suggests that loudness matches to a tone of the matched tinnitus frequency in both sensation level and sound pressure level are relatively good objective measures of tinnitus severity only with the no-hearing-loss subjects. Although recruitment is very often suggested as a possible explanation for the dissociation between self-reported annoyance and loudness measures, it cannot satisfactorily account for the poor correlation obtained in the present study. As discussed earlier, the similar sensation levels obtained in the loudness match to a white noise and that to a tone at the matched tinnitus frequency does not support the presence of recruitment in these subjects. Other auditory abnormalities associated with hearing loss and/or cognitive factors involved in the perceived severity of tinnitus may account for the poor correlation obtained.

Masking Levels

a. Ipsilateral Masking

To avoid entering the same datum twice and hence producing an artificial association between two variables, certain masking data were treated as missing and excluded from analyses. If tinnitus was matched in pitch to one of the fixed frequency maskers (0.5, 1, 2, 4, 6 or 8 kHz) in either one or both sessions, then the masking level obtained was entered as the masking level at the matched tinnitus frequency and the masking level at that fixed frequency was treated as missing for the subject. All data entered for descriptive statistics, t-tests and correlations were obtained in this way unless otherwise stated. (This method of treating the data does not apply to the figures.)

When tinnitus could be masked in one session but not another, the masking level obtained from the session in which masking was possible was taken as the masking level with that masker for the subject. Thus only when tinnitus could not be masked in both sessions was it considered not masked.

Inability to mask tinnitus probably does not reflect resistance to masking so much as the high thresholds usually encountered with these subjects at the high frequencies. The highest masker level presented was 90 dB SPL. When thresholds were high at the high frequencies only a low sensation level of the masker could thus be presented. Most inability to mask tinnitus appeared when maskers were located at the high frequencies. Of the 34 instances of inability to mask tinnitus (counted in individual sessions), 29 occurred at or above 4 kHz. The inability to mask tinnitus occurred at frequencies with high thresholds. 32 out of 34 instances occurred at frequencies with thresholds above 50 dB SPL and no such instances of inability to mask tinnitus ipsilaterally occurred with subjects 12 to 16 whose thresholds lay within the normal range (see above). Refer to Figures 3 and 4 for comparisons of the ipsilateral thresholds and the ipsilateral masking levels for individual subjects.

In order to make a meaningful comparison between threshold and masking levels, an 'adjusted threshold curve ' was constructed. An adjusted average threshold at one frequency was calculated by excluding the threshold measure of a subject at that frequency when masking at that frequency could not be achieved. Figure 2(a-c) gives a summary of ipsilateral masking of tinnitus at different masker frequencies in comparison to the average thresholds at different frequencies. Two threshold curves were presented, one representing the average thresholds for all subjects at all frequencies, another representing adjusted thresholds when particular threshold measures were taken out. The masking curve represents the masker level averaged over all subjects in the group as a function of masker frequency. Note that in practice these curves are usually quite close.

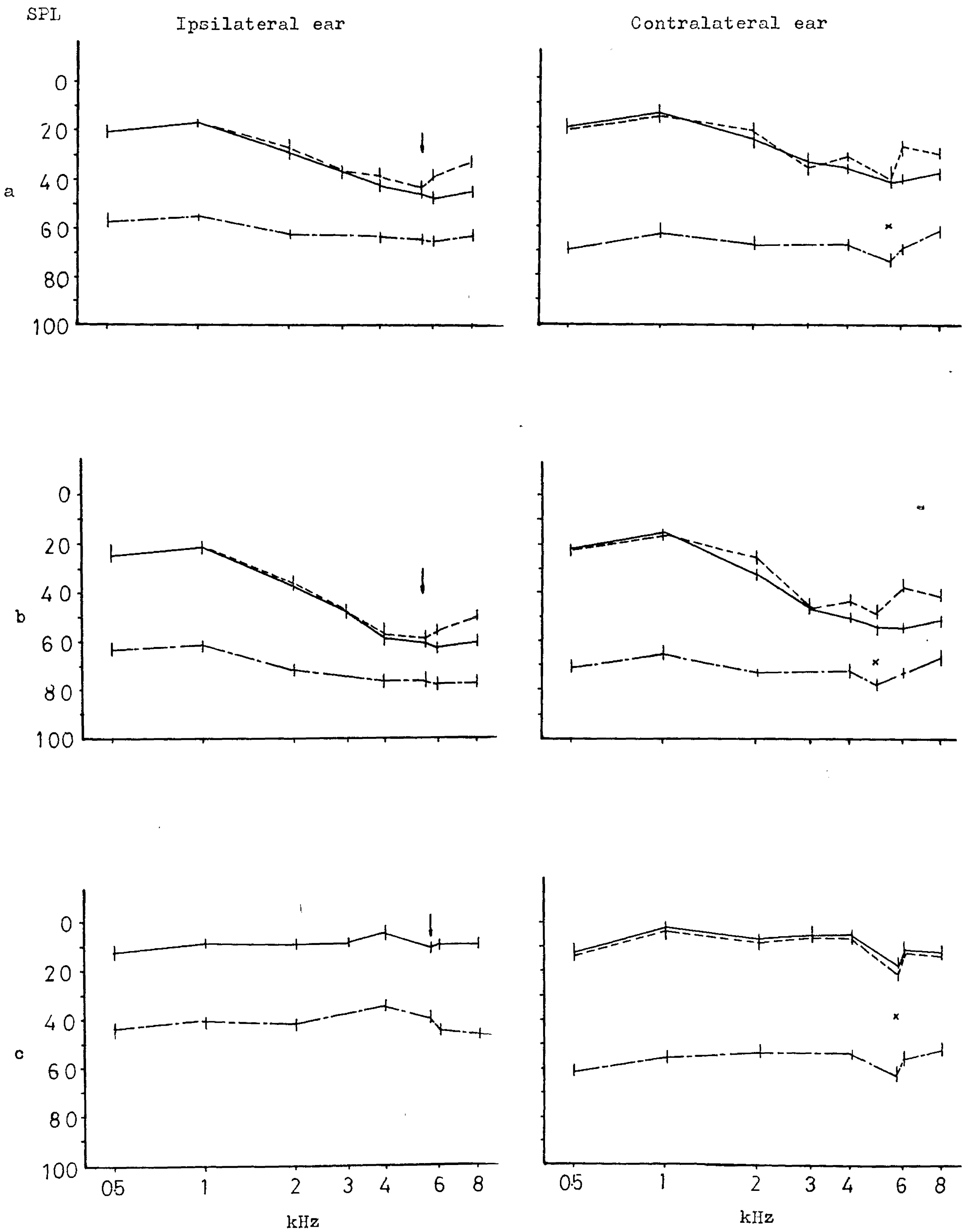
SPL
Ipsilateral ear
Contralateral ear
a
b
c
0
20
40
60
80
100
05
1
2
3
4
6
8
kHz
0.5
kHz

Figure 2 (a - c)

Two features of Figure 2 are worth noting. Firstly, all three masking curves are rather flat indicating that almost the same sound pressure level tone was required at different frequencies to mask tinnitus. Secondly, in terms of sensation level there is a difference between the two groups. As thresholds increased at high frequencies for the hearing-loss subjects, the threshold and masking curves tend to converge. Thus for these subjects lower sensation levels were necessary for the masking of tinnitus when high frequency tones were used than when low frequency tones were used. However, the threshold curve of the no-hearing-loss subjects is flat and the masking curve runs almost parallel to it indicating not only similar sound pressure level but also much the same sensation level maskers were needed to mask tinnitus at all frequencies.

The mean masking level was 26.5 dB SL for the white noise masker and 22.1 dB SL for a tone masker at matched tinnitus frequency. There was no significant difference in mean minimum masking levels (SL) between the white noise masker and the tone masker at the matched tinnitus frequency, so a noise masker was as effective as a tone masker at the matched tinnitus frequency.

There were no significant differences between the mean minimum masking levels (SL) of the hearing-loss and the no-hearing-loss subjects for any masker.

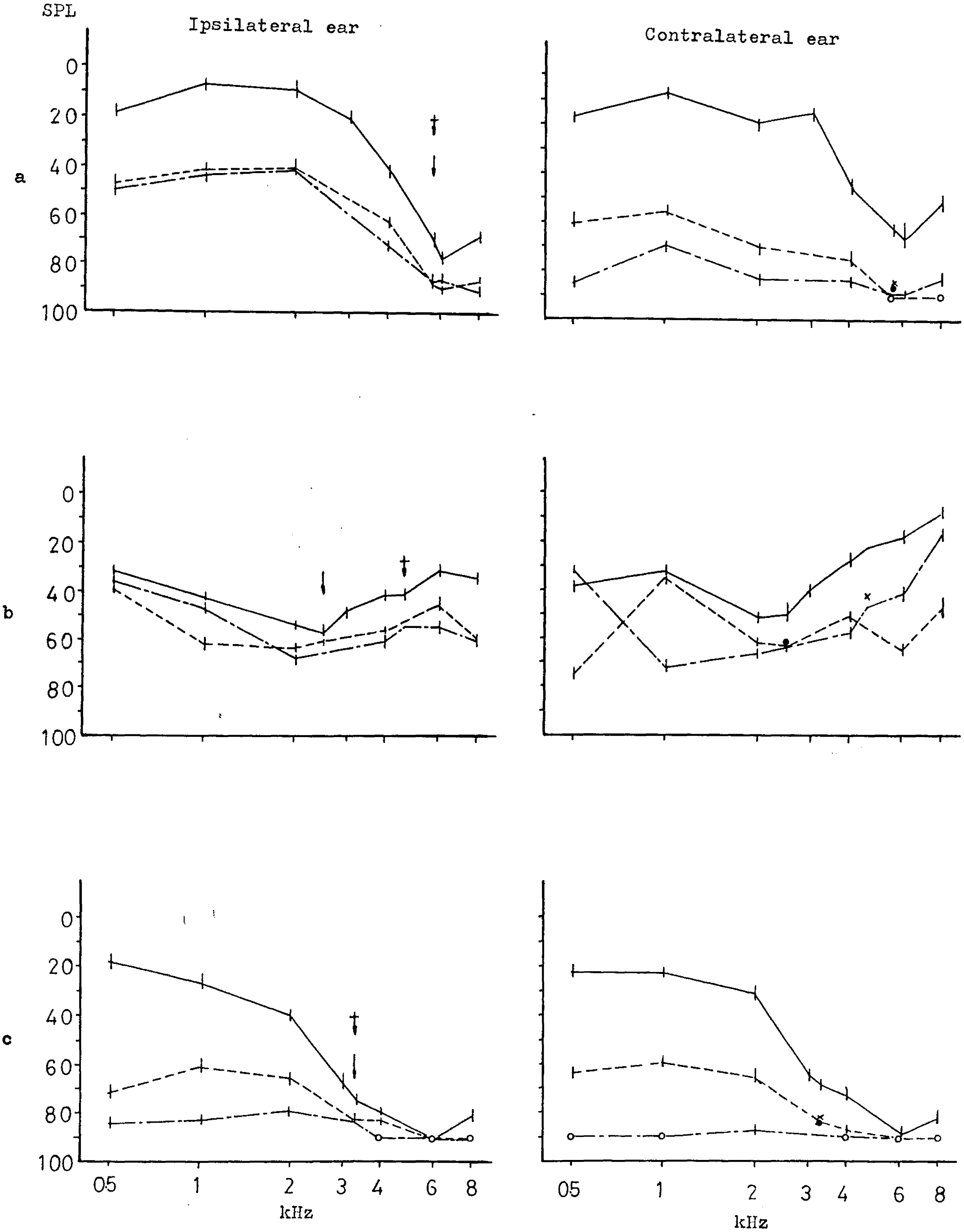
SPL
Ipsilateral ear
Contralateral ear
0
20
40
60
80
100
a
b
c
05
1
2
3
4
6
8
kHz

Figure 3 (a - c)

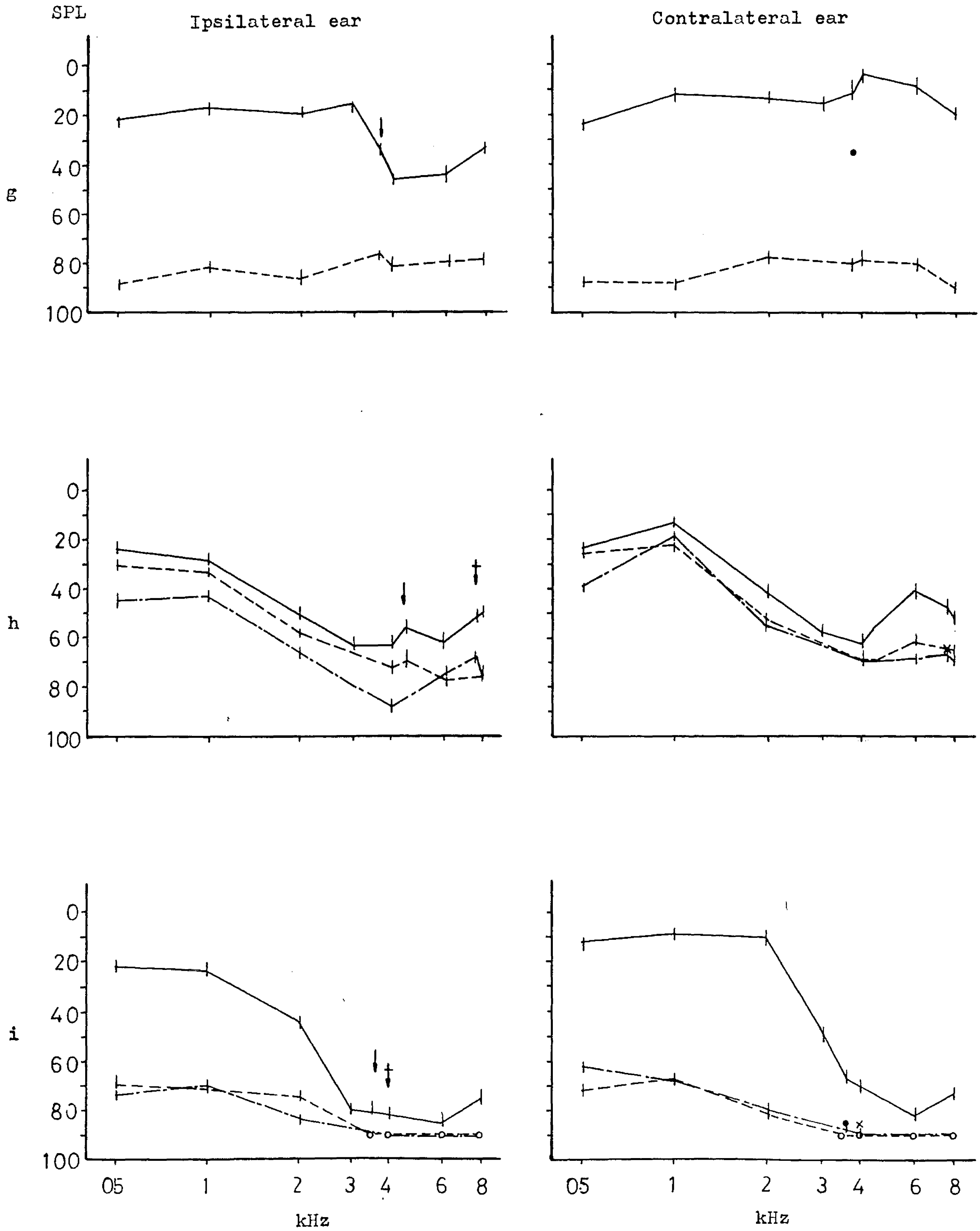
SPL
Ipsilateral ear
Contralateral ear
0
20
40
60
80
100
g
h
i
05
1
2
3
4
6
8
kHz

Figure 3 (g - i)

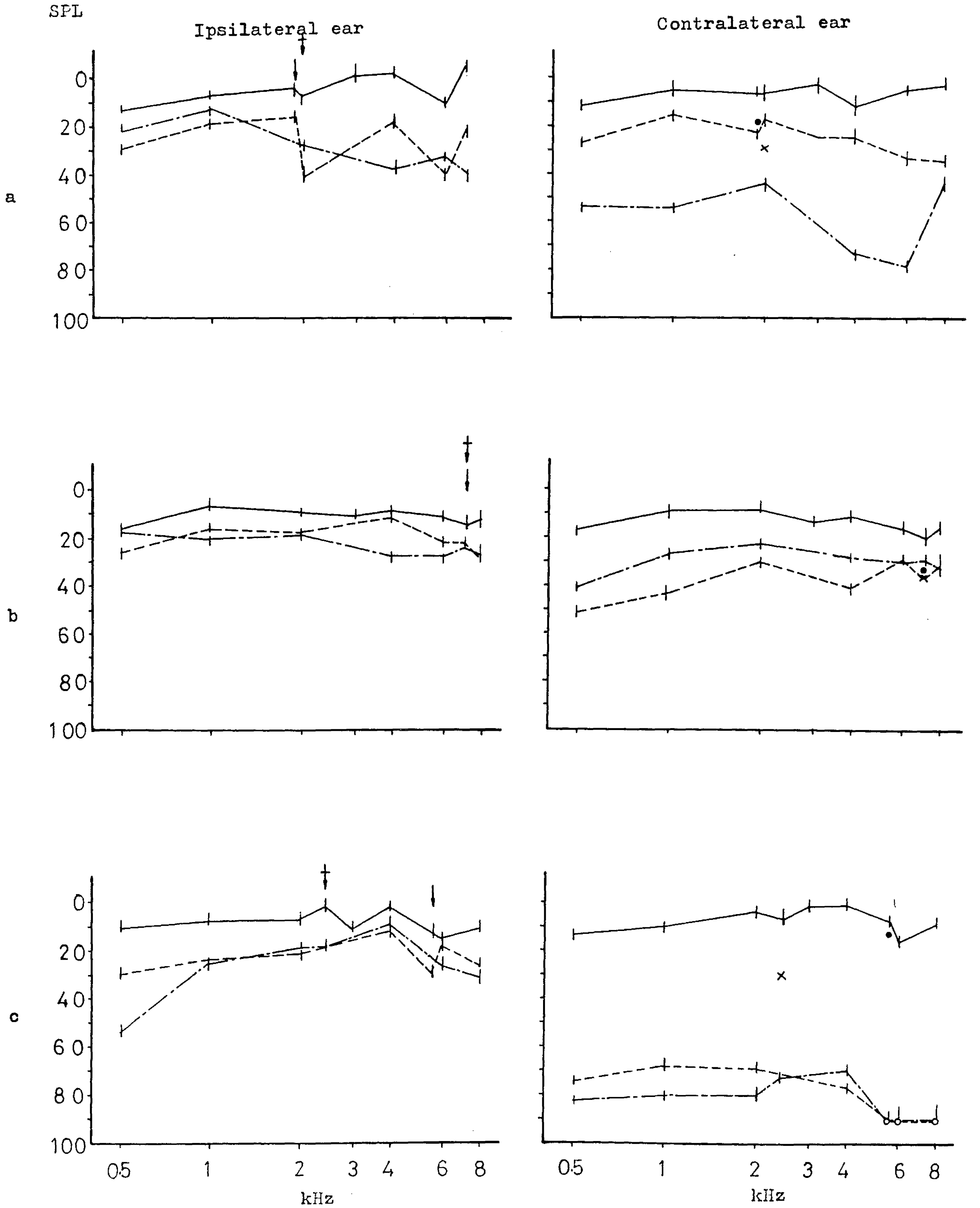
SPL
Ipsilateral ear
Contralateral ear
0
20
40
60
80
100
a
b
c
0.5
1
2
3
4
6
8
kHz

Figure 4 (a - c)

Individual masking data from the two different sessions are presented in Figures 3 and 4. Figure 3(a-k) shows the results for the hearing loss subjects and Figure 4(a-e) those from subjects with normal thresholds.

The feature which stands out from Figure 3 and Figure 4 is the great role played by individual differences in the masking of tinnitus. Tinnitus could easily be masked in some subjects while it was rather difficult to mask in others.

Apart from differences in masking levels, subjects also exhibited different types of tinnitus masking patterns. Feldmann (1971) described five different types of tinnitus masking, which can be used to classify the results of the present study. Subjects 1, 3, 5, 6 and 7 demonstrate convergence; relatively lower sensation level maskers were required at high frequencies than at low frequencies and so the masking and threshold curves converge at the high frequencies. Subjects 2, 4, 8, 10, 13 and 14 demonstrate congruence; their masking curves run very close and parallel to each other indicating equally low sensation level maskers at all frequencies. Subjects 11, 16, and 15 have their masking and threshold curves running parallel to but distant from each other, indicating equally high sensation level maskers at all frequencies. Subject 12 is the only subject who showed divergence; the masking and threshold curves run close to each other at the low frequencies and away from each other at high frequencies. No subject demonstrates persistance; tinnitus that could not be masked at any frequency even at very high masker level. It was difficult to assign subject 9 to any type of tinnitus masking pattern since there was not enough information available to do so. His tinnitus could not be masked at frequencies higher than 3 kHz.

Although there was great intersubject variability in the masking of tinnitus, masking in the two sessions did not differ greatly within subjects. As is evident from Figures 3 and 4, for almost all subjects the masking curves obtained from the two sessions had a similar shape although they sometimes differed in masking levels. The only exception was subject 5, whose tinnitus was resistant to masking in one session but could be masked at some frequencies in the other. It is possible that the difference in masking behaviour of this subject in the two sessions was a result of the subjects' adopting different criteria of masking in the two sessions. During the second experimental session when his tinnitus could not be masked, subject 5 remarked that his tinnitus did reduce in loudness in the presence of the masking tones. The reduction in loudness to a certain level might have been taken up as a criteria of masking in one session but not in another. No comparison between sessions could be made for subject 7 since only data from one session was available. The masking curves of subject 4 (Figure 3(d)) did not permit a clear comparison between sessions because tinnitus was not masked by 4 kHz and 6 kHz tones during one

b. Contralateral Masking

A white noise masker and tone maskers of different frequencies were also presented contralaterally to mask tinnitus. Results from subject 11 were excluded since she reported her tinnitus to be in the head and to sound as loud on one side as on the other. Results of contralateral masking of tinnitus were treated in a similar way to the results of ipsilateral masking. (Data from only one trial were available for subject 7.)

Figure 2(a-c) shows the average contralateral thresholds and masking levels of all subjects as a function of stimulus frequency. As with ipsilateral data, two threshold curves are presented. One represents the average contralateral thresholds of all subjects at different test-tone frequencies; another represents the 'adjusted average thresholds' (see above).

A number of similarities between ipsilateral and contralateral masking curves can be identified. Like the ipsilateral masking curves, the contralateral masking curves are flat suggesting much the same sound pressure level maskers were needed at all frequencies to mask tinnitus contralaterally. Both the ipsilateral and the contralateral thresholds of the hearing-loss subjects were relatively high at the high frequencies. Thus, the contralateral masking and threshold curves tend to converge at the high frequencies, indicating relatively low minimum masking level (SL) with high frequency masker than with low frequency maskers. The contralateral threshold and masking curves of the no-hearing-loss subjects are flat indicating almost the same sensation level maskers to mask tinnitus contralaterally at all frequencies. This was also the case for the ipsilateral masking of tinnitus of the no-hearing-loss subjects.

For a comparison between the individual ipsilateral and contralateral masking results in two masking trials for the hearing-loss subjects, refer to Figure 3; and the no-hearing-loss subjects Figure 4.

Compared to ipsilateral masking, there were more instances of inability to mask tinnitus contralaterally. The tinnitus of subjects 5, 6, 7 and 14 could not be masked contralaterally at some frequencies but could be masked at the same frequencies ipsilaterally.

There were a few cases where tinnitus could be masked in one session but not in another. (Refer to subjects 1, 3, 5, 6 and 10.) Except for these cases, masking levels between two sessions did not differ greatly. The masking curves of two sessions often ran close to each other. Moreover, the shape of the two masking curves from two sessions was generally similar indicating consistent masking behaviour over time. When adequate data were available for comparision, i.e., when there were not many instances of inability to mask tinnitus in a subject, the shape of the ipsilateral and contralateral masking curves of most subjects (subjects 2, 3, 7, 8, 9, 10, 12, 13 and 16) look very much the same. The exceptions are subjects 1, 4, 14 and 15. The contralateral masking curves of Subjects 1 and 4 appear much flatter than their ipsilateral masking curves. The tinnitus of subject 15 could not be masked contralaterally and the contralateral masking curves of subject 14 look quite different from his ipsilateral ones.

Like ipsilateral masking, individual differences in contralateral masking are considerable. Relatively high sensation level maskers were required to mask contralaterally the tinnitus of subjects 1, 3, 7, 9 and 14 than the tinnitus of subjects of 2, 8 and 13. The general trend is that when high sensation level maskers were needed for ipsilateral masking, high sensation level maskers were also necessary for contralateral masking. When low sensation level maskers were needed for ipsilateral masking, low sensation level maskers were also adequate to mask tinnitus contralaterally. The exceptions are subject 14, whose tinnitus could be masked with low sensation level maskers ipsilaterally but relatively high sensation level maskers contralaterally, and subject 15, whose tinnitus could not be masked contralaterally.

An important difference between ipsilateral and contralateral masking is the higher sensation level maskers necessary in the contralateral masking of tinnitus. (Since comparisons here are made between ipsilateral and contralateral masking levels and not among masking levels with different maskers. All data obtained were entered for analyses. For example, if a subject matched the pitch of his tinnitus to a tone of 6 KHz in one trial, then the masking level obtained will be entered as the masking level both at 6 KHz and at the matched tinnitus frequency in that session.) Higher mean minimum masking levels were needed with contralaterally presented maskers than with ipsilaterally presented maskers at 0.5 KHz ($t(14)=2.42$, $p<0.05$), 1 KHz ($t(13)=2.99$, $p<0.05$), 2 KHz ($t(12)=2.54$, $p<0.05$), 4 KHz ($t(10)=2.43$, $p<0.05$), 6 KHz ($t(9)=2.15$, $p<0.05$) and the matched tinnitus frequency ($t(11)=2.88$, $p<0.05$). A t-test showed no significant difference ($t(7)=1.80$, p n.s.) between the ipsilateral and contralateral masking level with the 8 KHz masker. However, the number of cases comparable here was small (7) because of frequent inability to mask tinnitus at this frequency. A lower masking level (SL) was also obtained with an ipsilateral noise masker than with a contralateral one ($t(14)=3.50$, $p<0.05$). Contralateral thresholds were not significantly different from ipsilateral thresholds except at 1 KHz ($t(14)=2.24$, $p<0.05$) and 6 KHz ($t(9)=2.67$, $p<0.05$) where contralateral thresholds were lower than ipsilateral thresholds. Although generally higher sensation level maskers were needed to mask tinnitus contralaterally than ipsilaterally, there were individual instances where the contralateral minimum masking levels (SL) were almost the same as or even lower than the ipsilateral minimum masking levels (SL). For example, the tinnitus of subject 3 was masked by a 1 KHz masker at 42.5 dB SL ipsilaterally and 36.7 dB SL contralaterally. The tinnitus of subject 8 was masked by an 8 KHz tone at 16.9 dB SL ipsilaterally and 15.1 dB SL contralaterally.

As with ipsilateral masking, a contralateral noise masker is as effective as a contralateral tone masker of the matched tinnitus frequency. There was no significant difference in the mean minimum masking levels (SL) between a contralaterally presented noise masker and a contralaterally presented tone masker of the matched tinnitus frequency.

Table 5 gives the correlation between the loudness matches and the contralateral minimum masking levels (SL). The loudness match to noise measured in sensation level was correlated with the contralateral minimum masking level (SL) of a noise masker. The loudness match to a tone at the matched tinnitus frequency measured in sensation level was significantly correlated with the contralateral minimum masking level (SL) of tone maskers at 0.5, 1, 4 and 8 kHz. This resembles the ipsilateral masking result where the loudness match to noise (SL) was significantly correlated with the ipsilateral masking level (SL) of a white noise masker and the loudness match to a tone at the matched tinnitus frequency (SL) was significantly correlated with the masking sensation levels of tone maskers.

Part Two: Results on Induced Tinnitus

Seven subjects participated in the second part of the experiment, three of them (subjects 14, 15, 16) had tinnitus and had also participated in the first part of the experiment. They are referred to as the 'tinnitus subjects'. The other four subjects (17-20), who did not usually experience tinnitus, are referred to as the 'non-tinnitus subjects'. The inducing tone was delivered to the ipsilateral ear (see above) of the tinnitus subjects and to the ear of the subjects' choice for the non-tinnitus subjects.

Subjective Reports

All subjects reported the induction of tinnitus in the ear to which the 1 KHz inducing tone was delivered. One subject (subject 20) also reported induced tinnitus in the opposite ear as well during some sessions. Except for subject 18 who sometimes heard a tone on top of his usually noisy induced tinnitus, all subjects perceived their induced tinnitus as one single sound sensation. All but subject 16 reported continuous rather than intermittent induced tinnitus. The induced tinnitus in two of the three tinnitus subjects (subjects 14 and 15) apparently masked their existing tinnitus in the same ear, but the other (subject 16) found the induced tinnitus occurring together with and distinct from his own tinnitus.

It appears that the pitch of induced tinnitus bears no direct relationship with the frequency of the inducing tone. The pitch of induced tinnitus was lower than that of the inducing tone for some subjects but higher in others and it could be noisy or tonal. Subjects 15, 16, 17 and 20 reported tonal induced tinnitus and subjects 14, 18 and 19 reported noisy induced tinnitus. While all subjects found the pitch of the induced tinnitus to be constant and unchanging over all the sessions, four subjects were aware of changes in the loudness of induced tinnitus between some sessions although it generally remained constant over most sessions. Annoyance and loudness of induced tinnitus were rated on five-point scales similar to those used in the first part of the experiment to give a subjective evaluation of the severity of induced tinnitus. No one rated induced tinnitus annoyance to be very or extremely annoying and only 1 subject rated it to be very loud, all the other subjects had lower ratings. The mean annoyance rating for the whole group was 1.7 and the mean loudness rating 2.6.

Verbal reports given immediately after the tinnitus sessions suggested that induced tinnitus did not appear immediately upon cessation of the inducing tone. There was a short silent gap between the termination of the 1 KHz inducing tone and the start of the induced tinnitus. When the induced tinnitus was perceived, it started softly and slowly grew in loudness to a steady level. It died off rather abruptly except for subjects whose induced tinnitus lasted longer than four minutes. Subjective reports agreed very well with results obtained from loudness matching and masking trials. An example of the response of a subject in a loudness matching session is given in Figure 5. The induced tinnitus of this subject started at a level of 17 dB SPL and grew to a steady level of 26 dB SPL and then died off abruptly after about 100 seconds at the level of 18 dB SPL. Subject 16, whose induced tinnitus lasted longer than 4 minutes, reported an abrupt decrease in the level of induced tinnitus in the first two minutes following which the level stayed low for a long period. The other subjects with induced tinnitus longer than four minutes did not report a sudden drop in the loudness of induced tinnitus during the experimental sessions.

Matched Frequency of Induced Tinnitus

Subjects matched the pitch of induced tinnitus to tones of different frequencies in two pitch matching sessions. This might be the result of real pitch changes in induced tinnitus. If, however, induced tinnitus pitch did change over sessions, subjects were not aware of it. All subjects reported that their induced tinnitus had the same pitch over all sessions. It is more likely that the different pitch matches were a result of the difficulty of the pitch matching task. In this context, note firstly that the pure tone sounded quite different from the induced sensation, particularly for subjects with noisy induced tinnitus. Secondly, the pitch matching task was carried out after the completion of the loudness matching task. This meant that for many subjects, the induced tinnitus had already disappeared when the pitch matching was performed and so pitch matching involved comparing the pitch of an external tone to the memory of the pitch of induced tinnitus. Even so, the pitch matches of each subject appeared fairly consistent. The difference in matched frequencies between the two sessions of a subject ranged from 10 Hz to 1200Hz.

Subject	Duration (in sec)	Max. Loudness Matches (in dB SL)	Matched Frequency (in Hz)
14	68.5	18.2	135/white noise
15	over 240.0	46.6	8500
16	over 240.0	33.7	3050
17	73.0	15.3	395
18	84.9	15.1	7000
19	98.4	6.2	8100
20	over 240.0	28.0	8700

Table 6 Duration, matched frequency and maximum loudness match of induced tinnitus of individual subjects

Subjects 14, 15 and 16 are 'tinnitus subjects' and subjects 17, 18, 19 and 20 are 'non-tinnitus subjects'. Note the three highest matches coincide with induced tinnitus duration of over four minutes.

Pitch matches from two trials of each subject were averaged to produce estimates of the induced tinnitus frequency. Matched frequency of induced tinnitus for each subject is given in Table 6. Subjective reports of tinnitus pitch in comparison to the pitch of the inducing tone and/or to the pitch of tinnitus agreed very well with objective matches, except for subject 15. Subject 14 insisted that his induced tinnitus was similar to white noise and chose a very low frequency match of 135 Hz when he was pressed to perform a match. He was also the only subject whose induced tinnitus could neither be masked by a tone at the matched induced tinnitus frequency nor the induced tinnitus frequency centred noise band. Therefore, it is tempting to believe that his pitch match was incorrectly performed.

Loudness Match of Induced Tinnitus

Two loudness measures were computed. The 30-second intervals on the audiometer chart were again divided in two equal-length epochs each representing a 15-second interval. The level of the comparison noise in the first epoch was averaged over two loudness matching trials of a subject to give the initial loudness match of induced tinnitus. The highest average level of the comparison noise from two consecutive epochs was taken as the maximum loudness match of induced tinnitus in that trial. Results thus obtained were averaged over the two experimental trials to give the maximum loudness match of induced tinnitus of the subject. These individual results appear in Table 6.

Table 7 gives the mean initial loudness and maximum loudness of

	Initial Loudness Match	Maximum Loudness Match
Whole Group	14.2 (9.8)	23.3 (13.7)
Tinnitus group	18.9 (5.8)	32.8 (14.2)
Non-tinnitus group	10.8 (11.5)	16.2 (9.1)

Table 7 Mean loudness level of contralateral white noise matched in loudness to the induced tinnitus.

Standard deviations are given in brackets.

induced tinnitus in both sensation level and sound pressure level. Induced tinnitus grew in loudness from a level of 14.2 dB SL to a level of 23.3 dB SL, an increase of 9 dB. It appeared that the tinnitus subjects had higher initial and maximum loudness matches than the non-tinnitus subjects; however, the number of subjects in each group was too small for meaningful statistical analysis.

Duration of Induced Tinnitus

The duration of induced tinnitus within an individual subject was quite consistent: the induced tinnitus of subject 15, 16 and 20 lasted longer than four minutes in all trials and the induced tinnitus of subjects 14, 17, 18 and 19 never exceeded 125 seconds in any experimental session. When subjects with induced tinnitus lasting longer than 4 minutes were excluded from calculation, a mean duration of 81.2 seconds was obtained. It appeared that there was a tendency for induced tinnitus to last longer and to be matched to a higher sensation level white noise in subjects with tinnitus. (see Table 6).

Masking of Induced Tinnitus

A white noise, a tone at the matched tinnitus frequency and a noise band of a critical bandwidth centred on the matched induced tinnitus frequency were used to mask induced tinnitus. All maskers were presented ipsilaterally. Contralateral masking was carried out only with the white noise masker. The highest average level of the masker from two consecutive epochs in a single trial was taken as the masking level of that trial. Results thus obtained from two trials were averaged to give the masking level with one masker for

	Maskers					
	Tone (SL)	Noise (SL)	ConNoise (SL)	Tone (SPL)	Noiseband (SPL)	Noise (SPL)
Whole group	39.0	29.3	48.3	55.6	47.3	40.4
	(18.1)	(15.5)	(24.3)	(15.0)	(7.3)	(14.9)
Tinnitus group	46.8	35.1	58.5	66.5	59.8	45.9
	(5.8)	(14.9)	(24.8)	(1.3)	(0.4)	(14.7)
Non-tinnitus group	35.1	24.9	40.7	50.2	41.1	36.3
	(21.7)	(16.5)	(24.3)	(26.1)	(7.4)	(15.7)

Table 8 Mean masking levels of induced tinnitus in sensation and sound pressure level

'Tone' refers to a tone masker at the matched induced tinnitus frequency. 'Noiseband' refers to a band noise of a critical band width centered at the matched induced tinnitus frequency. 'ConNoise' is a noise masker delivered to the contralateral ear.

Standard deviations are given in brackets.

the subject.

Table 8 gives the mean masking level of different maskers in SPL and SL. There was no significant difference in masking level between the noise masker and the pure tone masker measured in dB SL. Masking in sensation level was not available for the critical noise band masker as the critical noise band threshold of subjects was not measured.There was no significant differences in the masking levels measured in sound pressure level between the critical noise band masker on one hand and the white noise masker or the tone masker at the matched induced tinnitus frequency on the other.

Only the white noise masker was presented contralaterally to mask induced tinnitus of subjects; hence comparison between ipsilateral and contralateral masking of induced tinnitus could only be made with the white noise masker. The mean minimum sensation masking level (SL) with the contralateral noise masker was significantly higher than that with the ipsilateral one ($t(6)=3.77$ $p<0.05$).

The tinnitus subjects had consistently higher minimum masking levels (SL) with all maskers as well as more intense loudness matches (refer to Tables 7 and 8) than the non-tinnitus subjects.

Part Three: Comparison between Results from Two Parts of the Experiment

Subjective Reports

Subjective reports on tinnitus and induced tinnitus agreed quite well. Firstly, most subjects perceived both tinnitus and induced tinnitus to be a single sound sensation. Only two subjects reported tinnitus to be made up of two sounds and only one subject reported induced tinnitus to be made up of a tone and a noise at some sessions. Secondly, both tinnitus and induced tinnitus were more often continuous than intermittent. Fifteen out of sixteen subjects described their tinnitus as continuous and six out of seven had continuous induced tinnitus. Like tinnitus, the frequency characteristics of which could be quite varied as suggested by the different expressions chosen by subjects to describe it, induced tinnitus could be tonal or noisy. Moreover, it appeared from subjective reports that the pitch of induced tinnitus was less variable than the loudness of induced tinnitus. This was also the case for tinnitus. However, there were fewer reported fluctuations in both the pitch and loudness of induced tinnitus than in the pitch and loudness of tinnitus. While changes over sessions in the pitch and the loudness of induced tinnitus were noticed by none and 31% of the subjects respectively, 37% reported changes in the pitch and 81% in the loudness of tinnitus. The greater perceived fluctuation in pitch and loudness of tinnitus might be due to the availability of a longer and continuous period for comparison.

from the loudness match to tinnitus. Similar subjective loudness ratings were also obtained for tinnitus and induced tinnitus (see previous section).

Masking Levels

Masking of tinnitus with a white noise and a tone masker at the matched tinnitus frequency were compared to the masking of induced tinnitus with a white noise masker and a tone at the matched induced tinnitus frequency. Table 9 gives the mean minimum masking levels of tinnitus and induced tinnitus with the different maskers. No significant difference could be established between the mean minimum masking levels of tinnitus and those of induced tinnitus. However, induced tinnitus required a higher masking level (SL) than tinnitus (whole group) did if the noise masker was delivered to the contralateral ear ($t(17)=3.51$ $p<0.05$).

For both the masking of tinnitus and the masking of induced tinnitus a noise masker was as effective as a tone masker at the matched (induced) tinnitus frequency. The mean minimum masking level of tinnitus was not significantly different from that of a tone masker at the matched tinnitus frequency. Similarly, for the masking of induced tinnitus, a t-test showed no significant difference between the masking levels with noise and that with the induced tinnitus centred tone.

Both tinnitus and induced tinnitus require a higher sensation level noise masker to mask contralaterally than ipsilaterally.

CHAPTER FOUR DISCUSSION

Although the problem of tinnitus has been with us for a long time, the mechanisms responsible for the generation of tinnitus remain elusive. There is no general theory on tinnitus, therefore the results are not discussed in relation to a general theory. The results of different tasks conducted in the experiment are discussed separately.

The first part of this study investigated various aspects of tinnitus. These include the subjective ratings of severity, loudness matching, pitch matching and the masking of tinnitus.

The IHR survey (Coles 1984a) found that only 0.5 to 1% of adults (aged 17 or over) in the population reported whose tinnitus to have a totally debilitating effect on their lives. No subject in the present study reported tinnitus severity to such a disturbing degree. Most of them found their tinnitus only slightly to moderately severe. This probably reflects the relatively small number of subjects investigated here.

Although there was no difference in the subjective ratings of severity between the hearing-loss and the no-hearing-loss subjects, a more subtle difference concerning sleep disturbance was found between the two groups when various subjective ratings were examined together. Sleep disturbance was not a useful indicator of tinnitus severity in the hearing-loss subjects but it was effective in predicting tinnitus severity for subjects without hearing loss. Findings of the IHR survey (Coles 1984b) indicated that sleep disturbance was not necessarily related to tinnitus annoyance. Jakes et al (1985), in an attempt to access the relationship of tinnitus related annoyance and of subjectively and objectively measured tinnitus loudness, have shown the independence of sleep disturbance and other tinnitus complaints. They came to the conclusion that sleep disturbance which was not necessarily caused by tinnitus was often wrongly attributed to it. Although the hearing state of the tinnitus sufferers in these previous studies was not reported, it is probable that a great majority of them had hearing impairment: A recent study has shown that only a small percentage of tinnitus sufferers have normal hearing threshold and that the presence of tinnitus is strongly associated with hearing loss (Chung et al 1984). Therefore, while insomnia which is often used as a diagnostic tool for tinnitus severity is not a good predictor of tinnitus severity for those with hearing losses, it may be a reliable indicator of tinnitus severity for subjects with normal hearing threshold. However such subjects are less often encountered as sufferers in audiological or hearing clinics.

The pitch of tinnitus was generally constant and unchanging for most subjects as revealed by both the subjects' reports and the more objective measure of pitch matching results. Previous studies (e.g. Reed 1960, Nodar and Graham 1965, Graham and Newby 1962, Man and Naggan 1981) have suggested an association between the pitch of tinnitus and the underlying pathology. High pitch tinnitus was more often heard by patients with sensori-neural hearing loss (except for those with Meniere's disease). This also seemed to be the case in the present study as the average pitch match obtained for the hearing loss subjects was 5.4 KHz with most of them matching their tinnitus to tones over 4 kHz. Although it was not certain that the hearing losses of the subjects here was sensori-neural in origin, most of them had higher than normal thresholds at and above 4 KHz and six of them reported a history of noise exposure and/or acoustic trauma.

Cahani et al (1983) also reported on the distribution of tinnitus pitch of patients with and without hearing loss. The matched tinnitus pitch of the patients with no hearing loss had a tendency to concentrate on the lower frequencies (below 2 kHz) while that of the patients with hearing loss was concentrated on the high frequency range (4 kHz or above). This localization of tinnitus pitch is important in its implication. The distribution of tinnitus pitch into different frequency regions between hearing-loss and no-hearing-loss subjects suggests different sites of origin or different processes in the generation of tinnitus in these two groups of subjects. However, such a differential distribution of tinnitus pitch between the two groups was not established in the present study. There was no systematic difference in matched tinnitus frequency between the hearing-loss subjects and the no-hearing-loss subjects, and in fact, four of the five no-hearing-loss subjects matched their tinnitus to tones of over 4 kHz.

Tinnitus was matched in loudness on average to a white noise of 15.0 dB SL. A mean loudness match of 18.9 db SL was obtained when a tone at the matched tinnitus frequency was employed as the comparison stimulus. Most earlier studies had obtained loudness matches around 6 dB SPL (e.g. Fowler 1936, Man and Naggan 1981, Meikle and Walsh 1984). The result in the present study is, however, more comparable to the 23.9 dB SL match obtained by Johnson and Goodwin (1981). They used a tone at a frequency within the normal portion of the subjects' audiogram as the comparison tone , in order to counter the effects of recruitment. With the traditional way of matching the loudness of tinnitus to a tone at the frequency selected by the subjects during the pitch matching of tinnitus, the same subjects arrived at a much lower loudness match of 6.6 dB SL.

That the average loudness match to white noise was not higher than that to a tone at the matched tinnitus frequency in the present study ran contrary to what could be expected if recruitment was significant, for white noise, by its nature, is less susceptible to recruitment than a tone at the matched tinnitus frequency is. Although a more direct test of recruitment was not undertaken, it is possible that recruitment is substantially absent in the present study and this absence contributed to the relatively high loudness matching level obtained.

Loudness match to a tone of the matched tinnitus frequency is a good objective measure of tinnitus severity for the no-hearing-loss tinnitus sufferers only. For the no-hearing-loss subjects loudness match to a tone at the matched tinnitus frequency was significantly correlated with most of the subjective ratings of severity measured. However, it was not correlated with any subjective measures for the hearing-loss subjects. This is consistent with the general insignificant correlation between loudness matching measures and self-reported loudness ratings reported by other workers where most of the subjects were likely to be suffering from hearing loss (Fowler 1963, Jakes et al 1985).

Some phenomena associated with hearing loss may account for the poor correlation between loudness match and perceived severity of tinnitus in the subjects with hearing loss. Recruitment can render the loudness match of the hearing-loss subjects inadequate as a measure of tinnitus loudness. A lower than normal uncomfortable loudness level is not uncommon in people with hearing loss. A tone which is perfectly acceptable to those with normal thresholds may sound objectionably loud to those with hearing loss. On the other hand, subjects with hearing loss may have a different attitude towards their tinnitus from the usually younger no-hearing-loss subjects. General life dissatisfaction and distress associated with old age and/or hearing loss may also be attributed to tinnitus.

Results from the ipsilateral masking of tinnitus generally agreed with the findings of Feldmann (1971). Four of the five types of tinnitus masking described by Feldmann were identified: convergent, divergent, distant and parallel. None of these was similar to any pattern obtained when an external pure tone is masked.

Overall, the no-hearing-loss subjects produced a flat masking curve which can be classified as distant; similar sensation level maskers were required at all frequencies tested. However, for the hearing-loss subjects, maskers closer in frequency to the matched tinnitus pitch required a lower sensation level to mask the tinnitus. It appeared that the lower minimum masking levels were also related to the higher tone thresholds at these frequencies as the matched tinnitus frequency fell in the vicinity of frequencies with the greatest hearing loss.

Both the hearing-loss and no-hearing-loss subjects exhibited relatively flat masking curves indicating almost constant SPL maskers across frequency. This is not comparable to the shape of the psychophysical tuning curve obtained in the masking of an external tone. For practical reasons, such a result is important for it brings to question the usefulness of tailoring a tinnitus masker to the matched pitch of tinnitus for the purpose of providing relief to the sufferer. As a masker far away from the matched tinnitus frequency can be just as effective, using a masker which lies outside the speech frequency range or which poses less risk of further hearing damage would be desirable. Apart from its practical importance, the flat tinnitus masking curve also suggests that tinnitus is not processed in the same way as is a pure tone. The existence of typical psychophysical tuning curves in tinnitus sufferers using as the masked sound an external tone matched in pitch and loudness to the tinnitus were established in other studies (e.g. Penner 1985, Burns 1984). These studies suggest that the lack of frequency specificity in tinnitus masking is not a result of flat frequency selectivity and give stronger support to the suggestion that the processes involved in the masking of tinnitus and that of an external stimulus is different.

Tinnitus could easily be masked by presenting maskers to the contralateral ear. Moreover, results of such contralateral masking were generally similar to those of ipsilateral masking. Similarly, flat contralateral masking curves were obtained. Although higher SL maskers were needed to mask the tinnitus contalaterally than ipsilaterally, the difference was not great enough to be explained by a "cross-over" effect. Apart from central masking, contralateral masking is possible for an external tone through bone conduction. At high masker levels, the masker vibrates the skull and stimulates the opposite cochlea. Liden, Nilsson and Anderson (cited in Tyler et al 1984) suggested that a mid-frequency tone at threshold would require a noise of at least 40 dB SPL to mask the contralateral tone. The contralateral noise masker was only 7.7 dB higher than the ipsilateral one. The small differences (7.7- 15.8 dB) for different masker frequencies obtained here rule out the possibility of cross masking by bone conduction. For contralateral results would have to be 40 dB higher than ipsilateral results for crossmasking by bone conduction to occur. The differences here were calculated in terms of sensation level. Considering the fact that contralateral thresholds were consistently lower than ipsilateral thresholds (although not significant at all frequencies tested except at 1 and 6 KHz), the same sensation level in both ears would represent a lower SPL for the contralateral ear. That greater intensities were necessary to mask tinnitus contralaterally than ipsilaterally was also reported by Feldmann (1971) in pathologies of prebyacusia and industrial deafness. The similiarity in shape between the ipsilateral and contralateral masking curves coupled with the lack of frequency-specificity supports Penner's suggestion (Penner, 1985) that the masking of tinnitus occurs retrocochlearly, probably at some point where there is binaural interaction.

The hearing-loss and no-hearing-loss subjects did not differ in their subjective ratings, pitch matches, loudness matches and minimum masking levels. Such a result suggests that the tinnitus of these two groups of subjects results from the same underlying processes and that they share some common damage which do not show up in pure tone thresholds of the no-hearing-loss subjects. It has been shown that the hearing threshold is not a sensitive indicator of hearing damage and that some hair cell damage can occur after noise exposure without affecting auditory threshold. As a matter of fact two of the five no-hearing-loss subjects reported having history of noise exposure and further two identified acoustically traumatic events as responsible for initiating their tinnitus.

The second part of the experiment investigated the subjective aspects, loudness matching, pitch matching, duration and the masking of tinnitus that was temporarily induced.

Generally speaking, subjective reports and ratings on induced tinnitus agreed quite well with those of tinnitus. Like tinnitus, induced tinnitus was usually reported as a single, continuous sound sensation with generally constant pitch but occasionally changing loudness (over sessions). Despite similar loudness ratings and loudness matches and pitch matches, induced tinnitus was rated less annoying. The persistence and acquired significance of tinnitus might help explain its higher annoyance rating. Jakes et al (1985) found that many more subjects expressed objection to the persistence than to the loudness of their tinnitus. The more persistent ongoing tinnitus would thus be more objectionable and so more annoying than the short duration tinnitus induced experimentally in the present study. It is obvious that people should attach much greater significance to ongoing than to temporarily induced tinnitus. People's concern over the medical significance of tinnitus and their fear over its worsening might also have contributed to the greater annoyance experienced.

While some previous studies have reported that temporarily induced tinnitus was tonal in quality, others reported induced tinnitus to be noisy. Loeb and Smith (1967) and Atherley et al (1968) reported the induction of tonal tinnitus. Both of these studies employed long duration and very high SPL stimuli. Atherley et al exposed their subjects to stimuli of 110 dB SPL for five minutes. Loeb and Smith used stimuli with an initial level of 90 dB SPL. Subjects were exposed to the stimulus repetitively with increasing level until either a stimulus level of 120 dB SPL was reached or a temporal threshold shift of 40 dB was achieved.

Plaisted (1985) showed that tinnitus of a noisy quality could be induced with rather quieter stimuli. Stimuli of 80 to 105 dB SPL were used. He attributed the difference in the quality of the induced tinnitus to the higher level stimuli that were employed in the earlier studies. However, Hirsh and Ward (1952) with a view to studying the recovery processes of auditory threshold after acoustic stimulation was able to induce in subjects a noisy sound sensation upon the termination of a 3-minute 0.5 KHz tone with intensities of 100 to 120 dB SPL.

In the present study, induced tinnitus was reported to be tonal in some subjects and noisy in others. This is in disagreement with the findings of Plaisted (1985) and Kemp and Plaisted (1986), in whose studies similar stimulus conditions were employed. Subjects in different studies might have different interpretation as to what was meant by 'tonal' and 'noisy' depending, perhaps, on the explanations and instructions given by the experimenter. It is not unlikely that a narrow band noise would be described as noisy by some but tonal by others. As most subjects in the present study could match the pitch of their induced tinnitus quite consistently to an external pure tone, even those who maintained that their induced tinnitus was noisy, it is possible that the induced tinnitus was similar in quality to a narrow noise band with a definite tonal quality. More effort should be made on the explanation or demonstration to subjects as to what is meant by tonal and noisy so that meaningful interpretation and comparison of results between studies can be carried out.

As for tinnitus, the pitch of induced tinnitus varied considerably among subjects depending, it seems, more on the individual ear than on the stimulus used. Atherley et al (1968) maintained that the frequency of induced tinnitus was always lower than the frequency of maximum threshold shift and the difference between the maximum threshold shift and the frequency of induced tinnitus always equalled to the distance of a critical band width. The present study did not look into the pitch of tinnitus in relation to the frequency of the inducing stimulus. However, it appeared that the matched induced tinnitus frequency could be lower or higher than the frequency of the inducing tone and did not seemed to follow the relationship suggested by Atherley et al.

Subjective reports of constant and unchanging pitch of induced tinnitus was supported by rather consistent pitch matches over sessions. This is quite surprising when the apparent difficulty of the task is considered. The reliability of pitch matches of induced tinnitus over different sessions has already been noted by Loeb and Smith (1967) although there are important methodological differences between their study and the present one. In the present study, pitch matching was carried out after a loudness match was achieved; at which time the induced tinnitus had already disappeared in many subjects. The experimenter adjusted the frequency of the comparison tone according to the instructions given by the subject. In their study, subjects could adjust the frequency and intensity of the comparison tone which was presented to the contralateral ear soon after exposure to the inducing sound, and while the induced tinnitus was still present.

Unlike the results of the pitch matching of induced tinnitus, results regarding the duration of induced tinnitus were quite consistent with those obtained in previous studies despite the great differences in the characteristics of the inducing stimulus employed. In the present study, the average duration of induced tinnitus was 81.2 seconds (when subjects with longer than 4 minutes induced tinnitus excluded). Hirsh and Ward (1952) reported induced tinnitus which lasted for about 70 to 80 seconds. Kemp and Plaisted (1986) also reported induced tinnitus with similar duration of 80 to 90 seconds depending on the frequency of the inducing stimulus.

Similar temporal charcteristics of induced tinnitus to those found earlier were also observed here (Hirsh and Ward 1952, Kemp and Plaisted 1985). Typically there was an initial silence followed by a slow growth in induced tinnitus loudness to a steady level. It then reached a lower level and died off quite quickly.

For some subjects, induced tinnitus took a much longer period to die away. Three of the seven subjects in the present study had induced tinnitus which lasted for longer than four minutes. It appeared that tinnitus subjects were more liable to having longer lasting tinnitus than those subjects who did not usually experience tinnitus. This probably explains the relatively low incidence of longer-lasting induced tinnitus in Plaisted's subjects as no subjects in his study had tinnitus on a long term basis.

Overall, tinnitus subjects reported louder and longer induced tinnitus. A positive correlation between the duration and peak level of induced tinnitus was found by George and Kemp (unpublished). It would be interesting to know if people who reported relatively loud long-lasting induced tinnitus after exposure to loud sound are more liable to tinnitus or whether louder and longer-lasting induced tinnitus is a consequence of their ongoing tinnitus. Studying the behaviour of induced tinnitus in a subject may prove to be of help in predicting one's likelihood in developing ongoing tinnitus in later life.

As for the masking of tinnitus, an induced tinnitus frequency centred tone was as effective as the white noise masker. The white noise masker was also as effective as the critical band noise masker. This could hardly be expected if induced tinnitus behaved like an external pure tone. Since only a narrow band of frequencies within a critical bandwidth is responsible for the masking of a tone signal (Greenwood 1961, Patterson 1967), it would require higher SPL for the much wider band white noise masker than the pure tone and critical hand noise maskers to mask an external tone. Contralateral masking level was higher than ipsilateral masking level. The 19.0 dB difference was significant but once again was not great enough to be accounted for solely by a cross-over effect. In summary, results suggest that the masking of induced tinnitus is not similar to that of an external tone which is largely a peripheral phenomenon. Some retrocochlear processes may be involved.

The tinnitus subjects required consistently higher level maskers to mask their induced tinnitus non-tinnitus subjects. This result recalls the higher loudness match of induced tinnitus found in subjects suffering from ongoing tinnitus. Overall it appears that tinnitus subjects had stronger induced sensation after exposure to the 1 KHz inducing tone.

Results in the present study lead to the impression that temporarily induced tinnitus has similar characteristics to ongoing tinnitus. The subjective reports, loudness, pitch and the masking of tinnitus and induced tinnitus showed similarities. George and Kemp (unpublished) found a positive correlation between the levels of induced and ongoing tinnitus. Such similarity in behaviour and characteristics suggests similar processes in the generation of the two. It is possible that, at least for certain noise-related cases of tinnitus, tinnitus is temporary noise-induced tinnitus made permanent. If tinnitus and induced tinnitus can be shown to be related then studying the various charcteristics of induced tinnitus in relation to the charcteristics of the inducing stimulus can inform us about ongoing tinnitus just as the study of temporary threshold shift has produced valuable information about permanent threshold shift.

CHAPTER FIVE CONCLUSION

Apart from a relatively high loudness match, results on tinnitus generally agreed with previous findings. The flat tinnitus masking curve and the similarity between contralateral and ipsilateral results support the idea that tinnitus is 'masked' not at a periperal level but at a retrocochlear site where interactions between two ears occur.

With regard to the similarities in the subjective ratings, pitch matches, loudness matches and minimum masking levels between the hearing-loss and no-hearing-loss subjects , it is possible that the tinnitus of both groups share the same site of origin.

Some subtle differences do exist between the two groups of subjects. For the no-hearing-loss subjects, loudness match to a tone at the matched tinnitus frequency was significantly correlated to subjective severity ratings and minimum masking levels. No such associations were found for the hearing-loss subjects. Practically, this suggests that loudness match of tinnitus to a tone at the matched tinnitus frequency can be used as a reliable tool to predict tinnitus severity.

The lack of correlation between loudness match and subjective severity ratings or minimum masking levels in the hearing-loss group may be a result of the inadequancy of using sensation level as a unit of measuring tinnitus loudness. Factors like recruitment and a lower than normal uncomfortable loudness threshold can affect individual hearing-loss subjects to different degree. Since great intersubject variability in auditory performance is typical of the hearing-loss subjects, a measure which takes into account the subjective perception of loudness of each individual subject like the PLUs derived by Jakes et al (1986a) seems promising. On the other hand, subjective loudness measure is not only related to the physical characteristics of a stimulus. Cognitive factors, such as the perceived significance of tinnitus and the sense of helplessness induced, should be taken into account when subjective loudness is evaluated.

Tinnitus subjects had higher loudness matching, higher minimum masking levels and longer duration induced tinnitus than subjects who did not usually experience tinnitus, suggesting either a natural susceptibility in tinnitus subjects to have louder and longer induced tinnitus after exposure to loud sound or a susceptibility which is related to their ongoing tinnitus.

Results on the induction of tinnitus were generally similar to the results on tinnitus. This gives support to the idea that induced tinnitus and tinnitus are related phenomena; both may have a common origin. Tinnitus may very well be a temporary phenomenon made permanent as a result, perhaps, of a long history of exposure to loud sounds.

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APPENDIX 1

Questionnaire on onging tinnitus

Name :

Age :

Sex :

1. Where is the noise(s) in your ears/head located?

   _in the left ear

   _in the right ear

   _in both ears

   _in the head

   others____

   If in both ears, which side has a louder noise?

   _ in the right side

   _ in the left side

   _ almost the same for both ears

2. Do you usually hear one sound or more than one sound?

   _ one

   _ more than one, how many? _________

3. Is the noise(s) in your ears/head continuous or intermittent?

   _ continuous

   _ intermittent

4. The loudness of the noise(s) in your ears/head

_ is constant and unchanging

_ is usually unchanging but fluctuates at times

_ fluctuates widely

5. The pitch of the noise(s) in your ears/head

_ is constant and unchanging

_ is usually unchanging but fluctuates at times

_ fluctuates widely

6. How would you describe the noise(s) in your ears/head?

_ ringing

_ whistle

_ hissing

_ ocean roar

_ tone

_ hum

_ crickets

_ others (please describe) ______________________________

7. When did the noise(s) in your ears/head first appear?

_ has been there all the time

_ started about _______ months ago

_ started about ______ years ago

8. Can you identify any event which could or might be related to the initiation of the noise(s) in your ears/head?

_ No

_ If yes, what is it? ______________________________

9. Have you ever experienced unprotected exposure to very loud noises for more than six months? (e.g. working in a place where you have to shout in order to be heard, shooting firearms habitually without ear protection)

_ No

_ if yes, specify type of exposure ______________________

10. How would you rate the loudness of the noise(s) in your ears/head?

|——————|——————|——————|——————|

extremely soft	soft	moderately loud	very loud	extremely loud

11. Indicate how annoying you find the noise(s) in your ears/head?

|——————|——————|——————|——————|

not annoying at all	slightly annoying	moderately annoying	very annoying	severely annoying

12. Indicate the extend to which the noise(s) in your ears/head affect the quality of your life.

not at all	to a slight degree	to a moderate degree	to a severe degree	totally debilitating

13. Is your sleep disturbed by the noise(s) in your ears/head?

not at all	to a slight degree	to a moderate degree	to a severe degree	to a debilitating degree

APPENDIX 2

Questionnaire on induced tinnitus -- Subjects with ongoing tinnitus

Induced tinnitus ----Tinnitus group

Name :

Age :

Sex :

1. Where is the induced sound sensation located after the inducing tone ceases?

   _ in the same ear/side to which the inducing is delivered

   _ in the ear/side opposite to which the inducing is delivered

   _ in both ears/sides

   _ in the head

   If in both ears/sides, which side has a stronger sensation?

   _ the side to which the inducing tone is delivered

   _ The side opposite to which the inducing tone is delivered

   _ almost the same for both ears/sides

2. Is the induced sound sensation one sound or more than one?

   _ one

   _ if more than one, how many? ____________

3. The induced sound sensation is

   _ continuous.

   _ intermittent.

4. The induced sound sensation

   _ co-exists with the ongoing tinnitus in the same ear.

   _ is just like the ongoing tinntus but at a higher/lower level.

   _ block out the tinnitus in the same ear/in the opposite ear/in both ears.

5. Comparing the pitch of the induced sensation to the pitch of the inducing tone, the pitch of the induced sensation

   _ is lower than that of the inducing tone.

   _ is higher than that of the inducing tone.

   _ is almost the same as that of the inducing tone.

6. Comparing the pitch of the induced sound sensation to that of your ongoing tinnitus (in the same ear), the pitch of the induced sound sensation is

   _ lower than that of the ongoing tinnitus.

   _ higher than that of the onging tinnitus.

   _ almost the same as that of the ongoing tinnitus.

7. How would you describe the induced sound sensation?

_ ringing

_ whistle

_ hissing

_ ocean roar

_ tone

_ hum

_ crickets

_ others (please describe) ____________________________

8. Comparing the loudness of the induced sound sensation to that of the ongoing tinnitus,the induced sound sensation is

_ softer than that of the ongoing tinnitus.

_ louder than that of the ongoing tinnitus.

_ Almost the same as that of the ongoing tinnitus.

9. How would you rate the loudness of your induced sound sensation?

extremely soft	soft	moderately loud	very loud	extremely loud

10. Indicate how annoying you find the induced sound sensation.

not annoying at all	slightly annoying	moderately annoying	very annoying	severely annoying

11. The pitch of the induced sound sensation

_ is generally the same over all sessions.

_ is generally the same over most of the sessions but differences can be detected over some of the sessions.

_ differs from session to session.

12. The loudness of the induced sound sensation

_ is generally the same over all sessions.

_ is generally the same over most of the sessions but differences can be detected over some sessions.

_ differs from session to session.

APPENDIX 3

Questionnaire on induced tinnitus -- subjects with no ongoing tinnitus

Induced Tinnitus ---- non-tinnitus group

Name :

Age :

Sex :

1. Where is the induced sound sensation located after the inducing tone ceases?

_ in the same ear/side to which the inducing is delivered

_ in the ear/side opposite to which the inducing is delivered

_ in both ears/sides

_ in the head

If in both ears/sides, which side has a stronger sensation?

_ the side to which the inducing tone is delivered

_ The side opposite to which the inducing tone is delivered

_ almost the same for both ears/sides

2. Is the induced sound sensation one sound or more than one?

_ one

_ if more than one, how many? ___________

3. The induced sound sensation is

   _ continuous.

   _ intermittent.

4. Comparing the pitch of the induced sensation to the pitch of the inducing tone, the pitch of the induced sensation is

   _ lower than that of the inducing tone.

   _ higher than that of the inducing tone.

   _ almost the same as that of the inducing tone.

5. How would you describe the induced sound sensation?

   _ ringing

   _ whistle

   _ hissing

   _ ocean roar

   _ tone

   _ hum

   _ crickets

   _ others (please describe) ______________________________

6. How would you rate the loudness of your induced sound sensation?

|---------------|---------------|---------------|---------------|

extremely soft	soft	moderately loud	very loud	extremely loud

7. Indicate how annoying you find the induced sound sensation.

not annoying at all	slightly annoying	moderately annoying	very annoying	severely annoying

8. The pitch of the induced sound sensation

_ is generally the same over all sessions.

_ is generally the same over most of the sessions but differences can be detected over some of the sessions.

_ differs from session to session.

9. The loudness of the induced sound sensation

_ is generally the same over all sessions.

_ is generally the same over most of the sessions but differences can be detected over some sessions.

_ differs from session to session.